CHAPTER 5
Geology and Geochemistry of Sedimentary- Rock-Hosted Au Deposits in the Middle-Lower Yangtze River Area, Hubei and Anhui Provinces, P.R. China

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Abstract

The Middle-Lower Yangtze River area of the P.R. China contains several hundred sedimentary rock-hosted Cu, Fe, Au, S and polymetallic deposits and is part of one of the most important metallogenic belts in China. Upper Paleozoic to lower Mesozoic sedimentary rocks contain favorable stratigraphic sequences that host Cu, Au, and polymetallic deposits, as well as Carlin-type, distal-disseminated Ag–Ag deposits, and laterite-hosted Au deposits locally referred to as red earth Au deposits, such as the Shewushan Au deposit. Gold porphyry deposits also are present. Stratabound replacement Au deposits are hosted in specific strata of lower Triassic sedimentary rocks in southeastern Hubei Province in Tonglushan-Daye area, and in upper Carboniferous silty limestone strata in Anhui Province in the Tongling area. Carlin-type Au deposits in the Middle-Lower Yangtze River area, such as the Zhanghai Au deposit, locally are hosted in black Silurian phyllite and shale. The igneous-related Au deposits are associated with 160 to 180 Ma diorites in the Tonglushan (Daye) area and with 140 to 150 Ma porphyry plutons in the Jinlongshan-Fengshandong-Lijiawan area, and 80 Ma stocks at the JinJinzui porphyry Au deposit in southeast Hubei Province. In Anhui Province, most stratabound ores—such as at Tongguanshan, Xinqiao, Mashan, and Huangshiloashan—are associated with 137 to 153 Ma stocks. Red earth, or laterite-hosted deposits, are represented by the Shewushan Au deposit and are a product of supergene redistribution of Au.

摘　要

长江中下游地区有几百个产于沉积岩的铜、铁、金、硫和多金属矿床，是中国最重要的金属成矿带之一。上古生界至下中生界沉积岩有多个含矿层，产有铜、金和多金属矿床，以及卡林型，浸染状远原沉积岩型金矿床和红土型金矿床。局部产有斑岩型金矿。层控交代型金矿床产于鄂东南铜碌山－大冶地区的三迭系沉积岩和安徽铜陵地区上石碳系粉砂质灰岩中。个别卡林型金矿床，如张海金矿床产于志留系黑色页岩和粉砂岩中。铜碌山－大冶地区的金矿床与160-180Ma的闪长岩有关。鸡笼山－封山洞－李家湾地区的金矿床与140-150Ma的斑岩有关。金井嘴斑岩金矿床与80Ma的岩株有关。安徽铜陵地区大多数层控金矿床，如铜官山、新桥、马山、黄狮涝山等，与137-153Ma的岩株有关。以蛇屋山金矿床为代表的红土型金矿床是金的表生再富集的产物。

INTRODUCTION

The Middle-Lower Yangtze River area of the P.R. China contains a relatively large number of various types of sedimentary rock-hosted Au deposits, specifically, Carlin-type, distal disseminated or pluton-related Ag–Au deposits related to porphyries, and Cu–Fe skarns, as well as red earth or laterite-hosted Au deposits (fig. 5-1). These deposit types all are part of the family of sedimentary rock-hosted Au deposits, but they may owe their origin to several divergent processes. Deposit-type designations have been made on the basis of mineralogy, geochemistry, host rock type, and other geologic characteristics in individual deposits (see also, Chapters 1 and 2).

Investigations in the Middle-Lower Yangtze River area are a result of a joint collaborative agreement between the U.S. Geological Survey and the Tianjin Geological Academy (TGA) to study and compare sedimentary rock-hosted Au deposits in the P.R. China and in Nevada. The agreement calls for joint field visitations and compilations and has resulted in research on Carlin-type Au deposits in Nevada and in the Dian-Qian-Gui (Chapter 3) and Qinling fold belt (Chapter 4), P.R. China. A visit to the Middle-Lower Yangtze River area was conducted in Summer, 2000. An earlier report is contained in Li, Z.P. and Peters (1998) and an interactive Web-based database on sedimentary rock-hosted au deposits is available at–http://geopubs.wr.usgs.gov/open-file/of98-466/. This data base is tabularized in Appendix III with corrections of location and spelling. Field visits were conducted in the Yangtze River gorges and the Xiaojiapu, Zhanghai, and Shewushan Au deposits in southeastern Hubei Province and the Xinqiao, Mashan, and Huangshiloashan Au

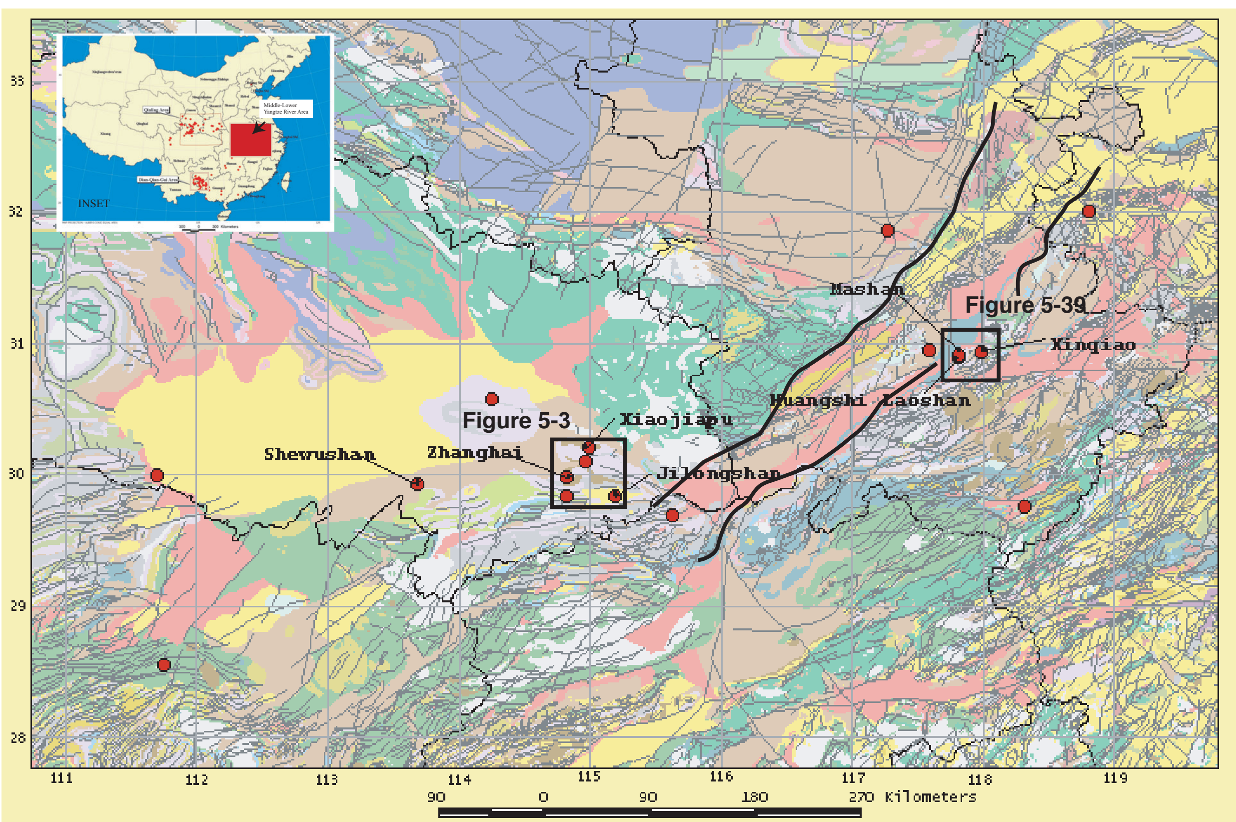


Figure 5-1A. Geologic map of the Middle-Lower Yangtze River area showing sedimentary rock-hosted Au deposits discussed in text. For legend of lithologic units, see figure 5-1B. For detailed location and additional deposit information, see Chapter 1 and Appendix III. Inset shows location of area in China.

EXPLANATION

STRATIGRAPHY

Quaternary

Q — Alluvium, mud, silt, loess; pebble beds in west Qinling area

Neogene

N — Mainly continental clastics, volcanics in Jinghong area

Eogene

E — Clastic rocks with volcanics in eastern Yunnan

Cretaceous

K, K2, K1 — Mainly continental and marine clastics with minor volcanics in western Qinling area

Jurassic

J, J3, J2, J1 — Continental clastic rocks with intrusives in western Qinling area

T-J — Incorporated beds; undivided

Triassic

T, T3, T2, T1 — Carbonates interbedded with sandstone and shale, volcanics in Zhongdian and Baoshan areas

P-T — Incorporated beds; undivided

Permian

P, P2, P1 — Continental clastic rocks interbedded with coal in Qinling area, volcanics in north Yunnan

MP-P — Incorporated beds; undivided

Mississipian-Pennsylvanian

MP, MP3, MP2, MP1 — Continental clastics; limestone interbedded with volcanics in Weixi area

D-MP — Incorporated beds; undivided

Devonian

D, D3, D2, D1 — Marine and continental clastics, volcanics in Jinghong area

S-D — Incorporated beds; undivided

Silurian

S, S3, S2, S1 — Marine clastics & mixed carbonate rocks in Yangtze region, vocanic rocks in west Qinling area

O-S — Incorporated beds; undivided

Ordovician

O, O3, O2, O1 — Continental carbonate and clastic rocks, shallow marine volcanics west Qinling

Cambrian

C — Clastic and carbonate rocks in Yangtze region

Precambrian

pC, pC3, pC2, pC1 — Undivided

INTRUSIVE ROCKS

1. Granitoids

gd — granodiorite

g — granite

xo — quartz-syenite (porphyry)

eo — quartz-monzonite (porphyry)

do — quartz-diorite (porphyry)

2. Diorites

d — diorite

3. Mafic rocks

n — gabbro

bm — diabase

4. Ultramafic rocks

s — peridotite

pi — pyroxenite (porphyrite)

5. Alkanline rocks

k — alkaline rocks

b — Basalts

x — syenite (porphyry)

VOLCANIC ROCKS

a — Andesites

AGE SUBDIVISIONS

Age subdivisions appear as suffixes to formation alphanumeric codes:

5 = Yanshanian

5-3 = Late Yanshanian

5-2 = Early Yanshanian

5-1 = Indosinian

4 = Variscan

3 = Caledonian

3-2 = Late Caledonian

3-1 = Early Caledonian

Figure 5-1B: Legend for the geological map of the Middle-Lower Yangtze River area, Figure 5-1A. Legend layout, style, and geological map unit classification scheme is adopted from the Geological Map of China (Cheng, 1990). See Cheng (1990) and Wang (1990) for additional details.

deposits in Anhui Province in the Tongling Mining District. Geochemical analysis was performed by TGA on samples collected from these deposits (Appendix IV) and S isotope analysis also was performed on mineral separates from these samples at the Mackay School of Mines, University of Nevada (Table 5-1). In addition, scanning electron microscopy was used to identify mineral species and textures in many of the samples in the U.S. Geological laboratories at Menlo Park.

In the Middle-Lower Yangtze River area, stratabound replacement Au deposits are hosted in specific horizons in both Triassic and Carboniferous silty limestone. Plutonic rocks and skarn also locally host some of these deposits. Carlin-type Au deposits in the Middle-Lower Yangtze River area, such as the Zhanghai Au deposit, are hosted in black, sandy Silurian phyllite and shale. Many sedimentary rock-hosted Au deposits in the Middle-Lower Yangtze River area are associated with 160– to 180–Ma diorites in the Tonglushan (Daye) area and 140– to 150–Ma geochemically intermediate porphyry plutons in the Jinlongshan-Fengshandong-Lijiawan area, and 80–Ma stocks at the JinJinzui porphyry Au deposit in southeastern Hubei Province (see also, Qang, Y.M. and others, 1996; Qi, X.X., 1996; and Chen, R.L., 1996b). Many of these deposits have similarities to porphyry-related Au deposits described by Sillitoe (1988). In Anhui Province, most stratabound ores, such as Xinqiao, Mashan, and Huangshiloashan are thought to be associated with 137– to 165–Ma intermediate stocks (Li, Z.P. and Yang, W.S., 1989). Mesozoic diorite dikes at the Carlin-type Zhanghai Au deposit fill important structures, but do not appear to be associated with Au deposition.

Some sedimentary rock-hosted Au deposits are not spatially associated with intrusive rocks, but are truly distal in nature, in that they are present over 1 km away in many cases from the causative intrusions. Due to intense pre- and post-mineral tectonism, the deposits contain complex geometric relations to the intrusive centers, but generally are hosted in the same parts of the stratigraphic succession in each district. The distal-disseminated deposit model belongs to the porphyry Cu or pluton-related mineralizing environment, and this model has a strong affiliation with upper crustal magmatism. The Carlin-type Au deposits, by comparison, cannot be definitively tied to magmatism. An underestimation of base-metal contents of mineralized systems, particularly from oxide ores, also has contributed to their problematic classification (see also, Hitchborn and others, 1996; Theodore, 2000). In addition, the Middle-Lower Yangtze River area contains a number of well-exposed and geologically well- documented sedimentary rock-hosted Au deposits that contain features, which aid in the study of the classification of these deposits.

Oxidation of sedimentary rock-hosted Au deposits has a direct effect on mining and milling costs and methods. Oxidation of sulfide minerals allows low cost heap-leach processing methods to be employed. Gossanous and sulfide ores in Au deposits in the Middle-Lower Yangtze River area are processed by both ball mill and flotation methods and by heap- and vat-leach methods. Red earth Au deposits (see also, Chapter 1) are processed directly by cyanide-leaching methods. Oxidation also reduces blasting costs because the rocks commonly are soft and can be directly excavated. The level of oxidation also affects Au contents in ore and provides structural information about the level of exposure of some of the deposits, because faults and other structures commonly are the foci for the deep oxidation zones. In addition, oxidation may obscure textural, mineralogical, and geochemical characteristics of sedimentary rock-hosted Au deposits that allow proper classification.

Stratigraphic nomenclature used in this chapter conforms, in most cases, to that proposed by the Ministry of Geology and Mineral Resources (1985) and updated by the Committee for Determining and Approving Terminology in Geology (1993). In many local mine areas formation names and names for structural features may differ because of old and new names and because of use of different names by different Provincial Geologic Bureaus. Assignment of nomenclature and age assignment of units to local mine areas may also vary, because a number of relatively independent geologic governmental agencies have conducted work in some areas. These differences in nomenclature use take place at local and provincial levels in daily usage, on mine maps and in written reports and published literature.

GEOLOGICAL SETTING

The Middle-Lower Yangtze River area contains several hundred Cu, Fe, Au, S and polymetallic deposits and is one of the most important metallogenic belts in China (Ge, C.H., and others, 1990; Zhao, Y., and others, 1990; Zhao, Y., 1991). Main rock types include local Archaean and a well-developed Proterozoic, Paleozoic and Mesozoic sedimentary rock sequences and a number of Mesozoic plutonic rocks (see also, Deng, S. and others, 1986; Yin, A., and Nie, 1996). Upper

Paleozoic to lower Mesozoic sedimentary rocks form the favorable host horizons for Cu, Au, and polymetallic deposits. Structural and tectonic framework, in combination with the sedimentary and igneous rocks, has directly affected the regional Au metallogeny in the Middle-Lower Yangtze River area.

Sedimentary rocks

Sedimentary host rocks for Au deposits in the Middle-Lower Yangtze River area mainly are late Paleozoic and early Mesozoic calcareous rocks. The entire Paleozoic section locally contains some Au deposits and occurrences (Yan, J.P., 1996). The following generalized descriptions of the Paleozoic section are presented to give a reference for the detailed descriptions of the individual geology of the Au deposits that follow. General distribution of these units by Period and lithology is shown on figure 5-1*A, B*.

Cambrian and Ordovician rocks are not known to contain abundant sedimentary rock-hosted Au deposits in the Middle-Lower Yangtze River area (Liu, X.C., and Wu., Y., 1988; Yan, J.P., 1996; Wang, Y.M. and others, 1996). Cambrian rocks include a 217– to 2,092–m-thick sequence of shallow marine facies sedimentary rocks. The Lower Cambrian series includes carbonaceous shale, siliciclastic rocks, calcareous shale, siltstone, marl, and dolomite. Middle-late Cambrian rocks mainly are argillic banded limestone, shale, and argillic limestone, interlayered with dolomite, and dolomitic limestone. The rocks are overlain by 142– to 1,653–m-thick of Ordovician, shallow- to deep-marine sedimentary rocks that consist of three sequences: (1) O_1, dolomite and dolomitic limestone, interlayered with knotty limestone, chert-banded limestone and shale; (2) O_2, knotty limestone, marlite, thick-bedded limestone and bioclastic limestone; and (3) O_3, marlite, limestone, shale, siliceous shale, organic-bearing material, claystone, and bedded chert.

Silurian rocks in the Middle-Lower Yangtze River area are represented by a 360– to 2,737–m-thick sedimentary sequence that is the most prospective horizon for Carlin-type Au deposits in the region, such as the Zhanghai Au deposit in Hubei Province and small occurrences in Anhui Provinces. These Silurian rocks consist of shale interlayered with quartz sandstone, local black shale, and siliceous shale of the Gaojiabian Formation (S_1g), claystone, argillic siltstone, interlayered with local phosphorite of the Fentou Formation (S_2f), and conglomeratic quartzite, and quartz sandstone of the Maoshan Formation (S_3m).

Devonian rocks in the Middle-Lower Yangtze River area are represented by the 1– to 323–m-thick, Upper Devonian Wutong Formation (D_3w) composed of continental facies clastics, which is divided into two members: (1) D_3w^1, quartz sandstone, conglomeratic quartz sandstone, ferruginous quartz sandstone interlayered with minor shale; and (2) D_3w^2, fine-grained sandstone, siltstone and silty shale, interlayered with claystone, ferrous siltstone, hematite and coal.

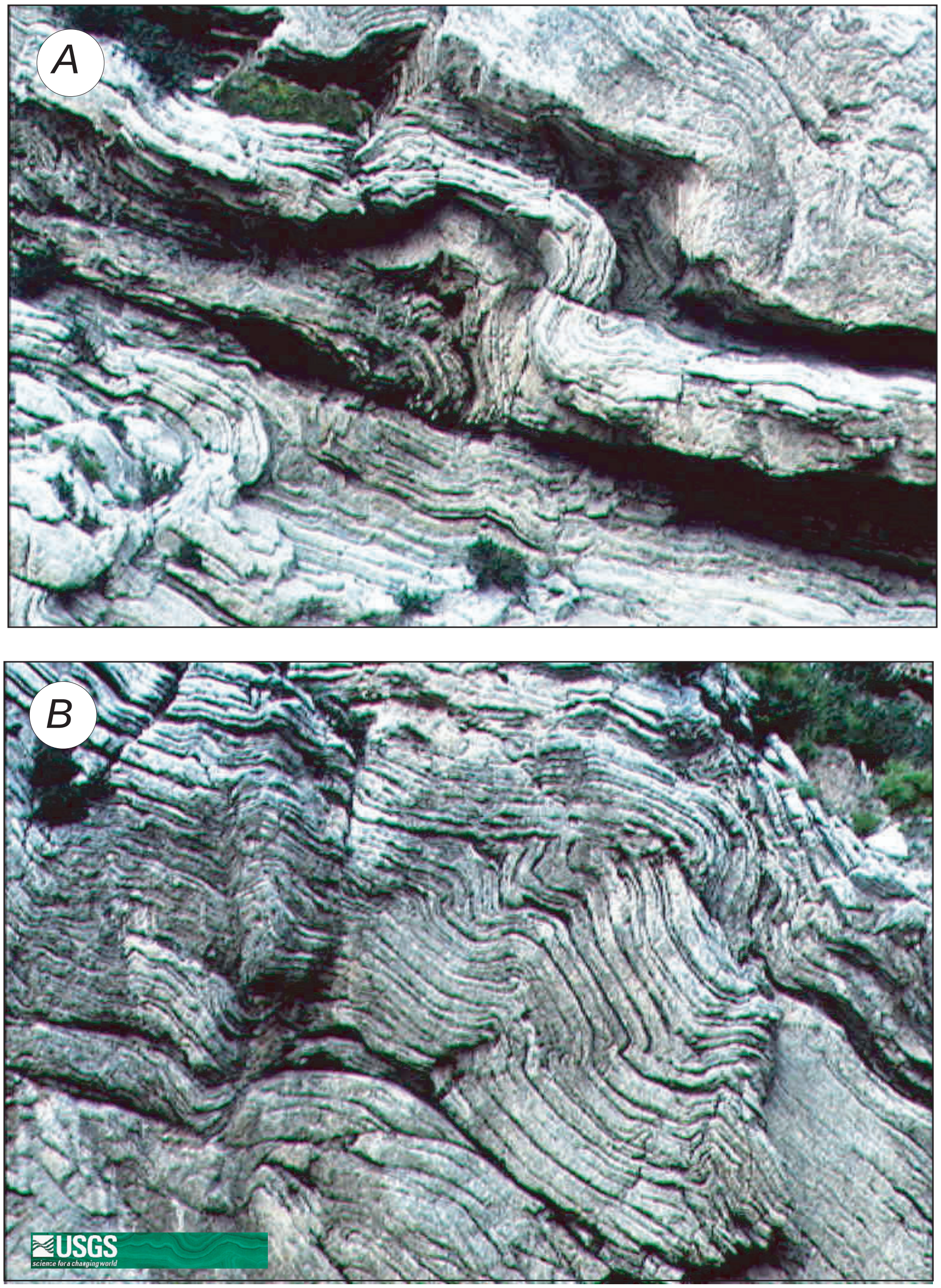


Figure 5-2. Photographs of folded Carboniferous strata in the Yangtze River gorge, west Hubei Province. (*A*) Box folding. Field of view is approximately 3 m wide. (*B*) Folding and shearing. Fieldof view is about 5 m wide.

Carboniferous rocks mainly are 53– to 238–m-thick, littoral marine carbonate facies and are an important host horizon for Cu, Au, Fe, and pyrite deposits, particularly in the Tongling area in Anhui Province. These rocks are well exposed in the gorges of the Yangtze River in west Hubei Province (fig. 5-2). The sequence consists of:

C_1: shallow marine facies carbonate rock interlayered with clastic rock of alternating continental and marine facies, divided into five formations:

C_1c: (Cishan Formation), 14 m thick. Lower: carbonaceous shale; upper: fine-grained sandstone.

C_1j: (Jinling Formation), sandstone, fine-grained sandstone and siltstone, local thick limestone, and ferruginous siltstone at bottom.

C_1g: (Gaolishan Formation): sediments of alternating continental and marine facies, such as fine-grained sandstone, argillic siltstone, calcareous argillite, silty shale and carbonaceous shale interlayered with lenticular hematite and coal beds.

C_1h: (Hezhou Formation): shallow marine facies limestone, marlite and argillic dolomite, interlayered with minor claystone and siltstone.

C_1l: (Laofudong Formation): dolomite, interlayered with dolomitic bioclastic limestone and marlite with chert bands or/ and nodule in the upper section

C_2h: (Huanglong Formation), widespread in the area, 30 to 132 m thick, divided into three members; the rocks are composed of dolomite, macrolitic limestone and bioclastic limestone (from the lower to upper).

C_3c: (Chuanshan Formation): bioclastic limestone and spherulitic limestone, interlayered with local microlic limestone 7 to 40 m thick.

Permian rocks are widespread in the Middle-Lower Yangtze area and are an important host horizon for deposits of Cu, Au, Fe, S, and coal. The rocks are present in two series of horizons (P_1 and P_2). The P_1 series is composed of littoral marine to shallow marine facies sedimentary rocks, such as carbonaceous shale, chert nodule-bearing limestone, siliciclastics, sandstone, and shale, and is divided into two formations—Qixia Formation (P_1q) and Maokou Formation (P_1m). The Qixia Formation (P_1q) is divided into 6 members (from lower to upper):

P_1q^1 is composed of calcareous shale and carbonaceous shale, interlayered with sandstone and lenticular limestone.

P_1q^2 is composed of bituminous limestone and bioclastic limestone, interlayered with dolomite or local crystalline limestone.

P_1q^3 is composed of siliciclastic rocks, siliceous shale, interlayered with chert nodule-bearing limestone, calcareous shale, and marlite.

P_1q^4 is composed of chert nodule-bearing limestone, interlayered with limestone and bioclastic limestone.

P_1q^5 is composed of siliciclastic rocks and siliceous shale interlayered with shale, argillite and marlite.

P_1q^6 is composed of limestone, chert nodule-bearing limestone and siliceous dolomite.

The Maokou Formation (P_1m) is composed of carbonate and siliciclastic rocks, siliceous shale, crystalline limestone, manganese-bearing shale, sandstone, and coal beds.

Upper Permian rocks (P_2) are divided into two formations (from lower to upper): Longtan Formation (P_2l) and Dalong Formation (P_2d).

P_2l is composed of silty shale, shale, carbonaceous limestone, siliciclastic rocks, and chert-banded or nodule-bearing limestone. The thickness is 16 to 73 m. The Wujiaping Formation, is the isogenetic out-of-facies sediment part of the formation, composed of chert-banded or nodule-bearing calcareous limestone and bioclastic limestone, interlayered with siliciclastic rocks, 25 to 7 m thick.

P_2d is composed of siliciclastic rocks, siliceous shale, silty shale interlayered with siliceous limestone, dolomitic limestone locally, and is 5 to 60 m thick. The Changxin Formation, the isogenetic out-of-facies sediment part is composed of banded limestone interlayered with bioclastic limestone and thin siliciclastic rocks, 22 to 160 m thick.

Triassic rocks are important hosts for Au and polymetallic ores in southeast Hubei Province in the Middle-Lower Yangtze River area and are represented by three series (T_1, T_2, and T_3). The 264– to 1,440–m-thick Lower Triassic Series (T_1) is widespread in the region and is composed of shallow-marine and littoral-marine facies sedimentary rocks. The lithology from the lower to upper parts is argillite, shale, argillic limestone, limestone, and dolomitic limestone. The T_1 strata compose the most important host horizons for deposits of Cu, Au, Ag, and Mo in southeastern Hubei Province. Gypsum and salt also are present inT_1 strata in the southeast part of Hubei Province. Rocks of the Middle Triassic (T_2) are composed of alternating sequences of continental and marine facies, such as dolomitic limestone, interlayered with anhydrite beds, brecciated limestone, sandstone, and shale. The Upper Triassic rocks (T_3) are composed of continental facies sandstone, siltstone, calcareous sandstone, and argillite interlayered with lenticular hematite beds.

Sedimentary rocks of Jurassic and Cretaceous age consist of continental facies sandstone, argillite and intermediate basic-intermediate acidic volcanic rocks

Igneous rocks

Yanshanian (185– to 76–Ma) magmatism was abundant and strong in the Middle-Lower Yangtze River area and is reflected by 240 mappable intrusive bodies and widespread volcanic rocks in 3,832 and 4,000 square km areas respectively (Qi. X.X., 1996). The igneous rocks are divided into a mantle-crustal and a crustal evolutionary series. The first series is further subdivided into the early Yanshanian igneous rocks, which were intruded during the Jurassic (J_2) at ≥135 Ma, and late Yanshnian igneous rocks, which were intruded during the Late Mesozoic and Early Tertiary between about ~135 to 70 Ma. The old intrusive rocks are controlled by east-striking shear zones consisting of six sub–intrusive belts with a diorite-quartz diorite (porphyry)-granodiorite association and are closely related to Cu, Au, and polymetallic deposits. The young intrusive rocks consist of both intrusive and eruptive rocks and are controlled by both east-striking and northeast- to north-northeast-striking faults present along three northeast-trending fault-bounded basins with gabbro (basalt)-gabbro-diorite (basaltic andesite)-diorite (andesite)-monzonitic granite (dacite)-granite (rhyolite) and syenite (trachyte)- K–feldspar granite (phonolite) associations and are related closely to Fe, S, and P ore deposits. The second series is Yanshanian-age rocks that consists of remelted crustal magmatic rocks that are controlled by the Jiangnan fault system (not shown on Fig. 5-1), are dominated by a granodiorite-granite association, and are related to Ag–Pb, and Zn ore deposits.

Structure

The Middle-Lower Yangtze River area is situated along the northeastern margin of the Yangtze craton (see fig. 1-9, Chapter 1). A long and complex tectonic evolution along this margin resulted in a complicated structure framework that includes fractures, faults, and fold systems, dÈcollement zones, and volcanic structures, all of which control the generation and development of igneous rocks and ore deposits (Zheng, Z.M. and others, 1984; Ji, X. and Coney, 1985; Hsu, K.J. and others, 1990).

Fracture Systems were developed in the area during the Jinning orogeny (850 ± 50 Ma), where the Yangtze and North China cratons collided and amalgamated, forming an east-striking sheared fracture system and a northeast- to north-northeast-striking compressional shear fracture system, which controlled sediment deposition, lithogenesis, and metallization. The east-striking shear fractures mainly are the Tongling-Lujiang fracture, Huangshi-Baoan fracture, Qingyang-Congyang fracture, and Yinshan-Hengshan fracture. The northeast- to north-northeast-striking compressional-shear fractures are the Changjiang (Yangtze River) fracture, Tancheng-Lujiang fracture, Huangshi-Lingxing fracture, and Qingyang-Dongzhi fracture (fractures not labeled on figure 5-1).

Major Folds developed during Indo-China tectonic events (225 to 190 Ma), when the Yangtze craton and North China craton again collided and amalgamated, and this led to supracrustal development of the Haiyang Arcuate fold system. Axes of folds in this system trends east in the Jiujiang area and northeasterly between Jiujiang and Nanjing, and again is east-trending between Nanjing and Zhenjiang (not shown on Fig. 5-1). Northeast- to north-northeast-trending folds overprinted this arcuate bend in the fold system during the Late Mesozoic and Early Tertiary (Zheng, Z.M. and others, 1984; Deng, S. and others, 1986; Hsu, K.J. and others, 1990; Wang, Y.M., 1996).

Décollement zones developed in the Middle-Lower Yangtze region during the Mesozoic during intense and frequent structural events. The dÈcollement zones are of various types and scales in Paleozoic and Mesozoic strata and are characterized by strata absence, tectonite development, blanket folding, interformational folding, and interformational fracture zones. In addition, nappes and outliers commonly are associated with these zones. The process of dÈcollement locally controlled granitoid intrusion and development of Fe, Cu, Au, S, and polymetallic ore deposits. Two major décollement zones are present: (1) the décollement zone between sedimentary rock series S-D_3 and $C_{1-2,}$ controls distribution of Cu–Au–S deposits in the Tongling metallogenic belt of Anhui Province and the Jiurui metallogenic of Jiangxi Province, and (2) the décollement zone between sedimentary rock series T_1 and T_{2-3} controls contact replacement deposit of Fe and Cu (Au) in the southeast metallogenic belt of Hubei Province (Yan, J.P., 1996).

Volcanic rocks formed the main structural pattern during late Mesozoic and Early Tertiary in the Middle-Lower Yangtze River area. Volcanic structures are of three types: (1) volcanic basin, (2) volcanic eruptive zone, and (3) volcanic eruptive centers. Three volcanic basins present in the region are: the Lujiang-Congyang volcanic basin, the Nanjing-Wuhu volcanic basin, and the Daye volcanic basin. These are bounded by east-striking and north-northeast-striking fracture systems and produced rhomb-shaped basins (basins not labeled on fig. 5-1*A*). Some middle- to large-size Fe, S, Cu, and Au deposits are present in these volcanic basins.

Gold Metallogeny

The Middle-Lower Yangtze River area is a main Au-ore-forming area in which a variety of Au deposits are present. Three types of Au deposits are recognized: (1) Yanshanian (185– to 67–Ma) magmatic hydrothermal (pluton-related) Au deposits; (2) supergene-oxidation-enrichment (red earth, laterite-hosted) deposits; and (3) micro-disseminated (Carlin-type) Au deposits (Liu, X.C. and Wu, Y., 1988; Liu, B.G. and Yeap, 1992; Cun, G., 1995; Wang, Y.M., and others, 1996; Li, Z.P. and Peters, 1998).

Pluton-related Au deposits are the main types of Au deposits in the Middle-Lower Yangtze River area and account for 90 percent of the total proven reserves of Au ore in the area (Kuo, T., 1957; Yan, M.Z., and Hu, K., 1980; Wang, Z., 1982; Fan, P.F., 1984; Chen, P.L., 1996a,b; Rei, R.F., and others, 1999). Formation of the Au deposits is closely related to intrusion of early Yanshanian (185 to 67 Ma) diorite-granodiorite. The Au deposits are associated with or accompanied by Cu and polymetallic ores and are controlled by northeast- and north-northeast-striking basement faults and by detachment faults in the overlying sedimentary rocks. The Au deposits can be divided into contact replacement, porphyry, and interformational hydrothermal-fill deposit types. Changes in geochemical elemental ratios of ores, brought about by oxidation in these distal-disseminated deposits, cause some high-level pluton-related occurrences to have Carlin-type geochemical signatures, particularly due to enrichment of As, Sb, and Hg in both Carlin-type systems and in distal-disseminated Ag–Au deposits (see also, Albino, 1993).

Pluton- or porphyry-related Au deposits are described as distal-disseminated Ag–Au deposits by Cox and Singer (1990, 1992) and Cox (1992), polymetallic replacement deposits (Mosier and others, 1986; Morris, 1986), or Au-porphyry deposits (Sillitoe, 2001). These deposits have distinctions from the Carlin-type deposits, but are part of the overall sedimentary rock-hosted Au deposit family (see Chapter 1). They contain Ag and Au in disseminations, replacements, and stockworks of narrow quartz-sulfide veinlets and (or) Fe oxide-stained fractures in sedimentary rocks, and they contain some diagnostic trace elements—specifically Zn, Mn, Cu, and Bi—which suggest that they may be pluton-related (Cox and Singer, 1992; Hitchborn and others, 1996; Margolis, 1997). Ores in the Middle-Lower Yangtze River area contain minerals with these elements and commonly also contain celestite, fluorite, pyrrhotite, and arsenopyrite. Fluids involved in the generation of these deposits include a significant magmatic component (Li, Z.P. and Yang, W.S., 1989).

Although many distal-disseminated Ag–Au deposits are hosted by sedimentary rocks, they are distinct from Carlin-type Au deposits. For instance, deposits of this type show significant K-metasomatism, which is comparatively rare in the Carlin-type deposits. In addition, many distal-disseminated Ag–Au deposits contain more Ag and base metals than most Carlin-type deposits (Peters and others, 1996).

Porphyry systems consist generally of large volumes of rock that are characterized by disseminated concentrations of pyrite, chalcopyrite, bornite, molybdenite, or Au and a number of other prograde and secondary sulfide minerals. These minerals form in intensely fractured rocks filled by stockwork veins or disseminated grains in hydrothermally altered porphyritic intrusions and (or) in their hydrothermally altered adjacent wall rock (Peters and others, 1996; Theodore, 2000). Polymetallic replacement deposits in the Middle-Lower Yangtze River area may be directly related to porphyry Cu systems that contain relatively high concentrations of Au compared to porphyry Cu systems elsewhere. Much mineralized rock in these systems owes its origin to fluids that were expelled during the process of crystallization of genetically associated magma, typically present locally in intrusive centers that represent composites of a number of closely associated igneous phases and associated ore-types, such as Au skarns and polymetallic veins.

Red earth or supergene oxidation enrichment (lateritic) Au deposits is a product of long-lived humid and hot weather environments in the area that have facilitated formation of supergene oxidation enrichment Au accumulations (Webster and Mann, 1984; Butt, 1989; and Chapter 1). On the basis of ore-forming characteristics, these Au deposits can be divided into gossan and residual slope settlement (lateritic) types. In the Middle-Lower Yangtze River area, there are 250 gossan Au occurrences in oxidation zones above sulfide-deposits that mainly are hosted mainly by $C_{1\text{-}2}$ strata. Lateritic Au deposits are present mainly in Ordovician-Silurian strata at the west, and south margins of the Middle-Lower Yangtze River area and formed in three stages. The first stage was the formation of the Au-source bed or Au proto ore; the second, Au–bearing tectonite zones resulting from nappe movement; the third, supergene oxidation enrichment to Au ore.

Lateritic Au or red earth deposits are formed throughout South China where Au-bearing carbonate rocks, clastic rocks, contact zones of granite, volcanic, and metamorphic rocks are exposed to protracted tropic climate weathering. Red earth deposits commonly are located in the topographic areas of medium-low mountains, which consist of low hills and plains with extensive valley and river alluvial erosion. The areas of Nanling, the southeast coast of China, Guizhou, Yunnan Provinces and middle and lower parts of the Yangtze River area, particularly the large Shewushan Au deposit, are the main locations of lateritic Au deposits.

Carlin-type Au deposits mainly are present along an east-trending ore belt in Hubei Province from Jiayu County through Fangshan of Chongyang County, Fushui of Tongshan County to Fenglin of Yangxin County. Paleozoic silty carbonate and (or) argillaceous rocks host the Au deposits. Mineralized rocks characteristically have a Au–Sb (As–Hg–Tl) element association, and generally they are controlled by intersections of nappes and northeast-striking faults. Characteristics considered for Carlin-type Au deposits, in general are similar to those indicated by Berger (1996), Peters and others (1996), Arehart (1996), and Hofstra and Cline (2000). These characteristics commonly include submicron-sized Au, generally in the crystal structure of disseminated arsenical pyrite or marcasite. The host rocks are variably silicified, decalcified, and argillized. Mineralogy in the ore zones of Carlin-type deposits includes Au–bearing arsenian pyrite, marcasite, stibnite, realgar, orpiment, cinnabar, Tl–sulfide minerals, rare Ag–Sb and Pb–Sb sulfosalt minerals, sphalerite, and Ni sulfide minerals (see also, Peters and others, 1998, 2000). A magmatic association with Carlin-type Au deposits has been suggested by Sawkins (1983), Sillitoe and Bonham (1990), and Ressel and others (2000a,b).

The main geochemical elements associated with Carlin-type Au deposits worldwide are As, Sb, Hg, Zn, and Ba (see also, Hill and others, 1986; Dean and others, 1988) and trace amounts of Tl, Pb, Cu, Co, Ni, and P, as well as some rare earth elements that are abundant. Tellurium and Bi usually are absent to extremely low in Carlin-type deposits but may be elevated in distal-disseminated deposits (Albino, 1993). Base metals usually are at background levels. The geochemical signature of the Carlin-type Au deposits is typically Au—Au/Ag ratios generally are <1 (that is, Ag is not of significant economic value)—As, Sb, and Hg. Silver generally is much higher in the distal-disseminated, pluton-related sedimentary rock-hosted Au deposits (Cox and Singer, 1992; Theodore, 2000).

DESCRIPTION of DEPOSITS

Sedimentary rock-hosted Au deposits in the Middle-Lower Yangtze River area mainly are gossanous ores that are associated with contact and replacement zones around Mesozoic stocks and plutons in the southeastern Hubei Province and the Tongling Mining District in Anhui Province and they are described below. In addition, a Carlin-type Au deposit and a red earth, laterite-hosted Au deposits are described below. The descriptions summarize data and information compiled from a number of different sources and from results of field and laboratory investigations, which include scanning electron microscope analysis, analytical geochemistry, and sulfur isotope analysis of selected sulfide ores. Information obtained for the deposits is not complete or uniform; the compilations are designed to provide enough information to characterize the deposits and allow comparison to other sedimentary rock-hosted Au deposit in China and Nevada.

Southeastern Hubei Province

Southeastern Hubei Province contains some of the largest porphyry-related Cu–Fe skarn deposits in P.R. China (Huang, Y. and others, 1957) and has reserves of 500 tonnes Au, 5,000 tonnes Ag, 100,000 tonnes each of W and Mo, 5 million tonnes Cu, 5 million tons $SrSO_4$ ore, and 700 million tonnes Fe ore with between 32 to 60 percent Fe, and 50,000 tonnes of >50 percent Fe ore. The southeastern Hubei area is located west of the Yangtze River and the City of Huangshi (fig. 5-3). The main geologic features are west northwest-trending, southeast plunging, district-scale anticlines and synclines that are spaced about 20 km from crest to crest. The anticlines contain northwest-elongated 120–to 180–Ma-age plutons that are surrounded by Cu–Fe skarn and other polymetallic and precious metal, pluton-related deposits along their contacts (fig. 5-3). The largest skarn deposit is the Tonglushan Cu–Fe skarn. In addition, a cluster of porphyry Cu–(Mo–Ag–Au) deposits is present at Jilongshan-Fengshandong-Lijiawan and a Au porphyry at JinJinzui is present near Tonglushan (fig. 5-3). A number of metallogenic ages are suggested by intrusive ages and crosscutting relations at around 160 to 180 Ma (Cu–Fe), 120 to 130 Ma (Au–Ag?), and at about 80 Ma (Au). Sedimentary rock-hosted Au deposits in southeastern Hubei Province are characterized by gossans at Xiaojiapu, the Carlin-type Au deposit at Zhanghai (fig. 5-3), and the red earth (laterite-hosted) Au deposit at Shewushan (fig. 5-1).

Tonglushan (Daye) Cu–Fe skarn deposits

The Tonglushan Cu–Fe skarn deposit is located about 15 km from Daye City at the northwestern contact of the 180 Ma Yangxin pluton (figs. 5-3, 5-4). The deposit has been worked for more than 2,000 years and is a large-size, high-grade, Cu-dominant polymetallic skarn deposit (Huang, Y. and others, 1957; Fan, P.F., 1984; Ge, C.H. and others, 1990) (*Tong* means Cu in Chinese). The modern extent of the deposit was defined by geologic mapping, sampling, and exploration geophysics between the 1920s and 1960s. The main Tonglushan ore zone is 2 km long and 300 to 1 km wide and consists of 11 northeast-striking orebodies. In 1984 the deposit produced 4,000 tonnes Cu ore per day from open pit and underground mines.

Host rocks for the Tonglushan Cu–Fe skarn deposits are middle to lower Triassic calcareous sedimentary rocks. The sedimentary rocks are surrounded by the Yangxin porphyritic quartz monzonite and form complex roof pendants and megaxenoliths (figs. 5-4, and 5-5). Ghost stratigraphy can be reconstructed through these pendants and megaxenoliths

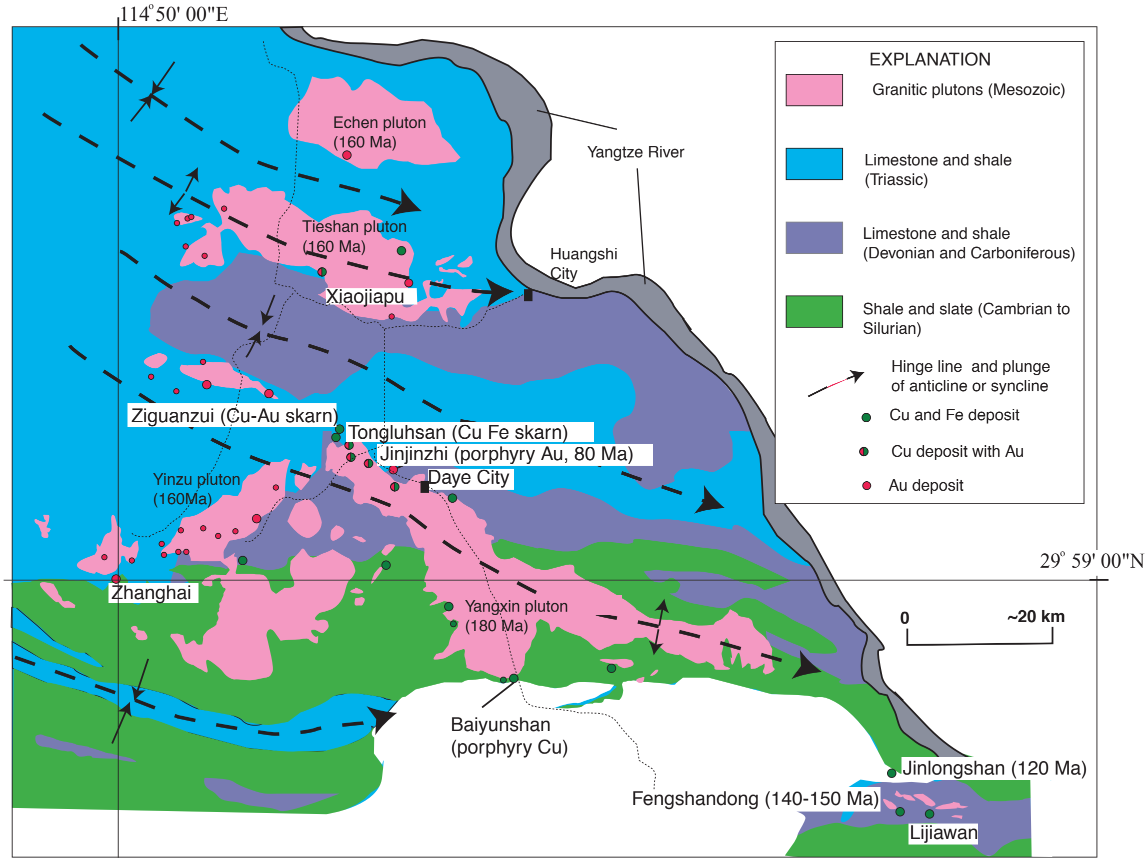


Figure 5-3. Simplified geology of southeastern Hubei Province, Middle-Lower Yangtze River area. Main geologic elements are the southeast-plunging folds of lower Paleozoic, to Triassic sedimentary rocks that are intruded by Mesozoic intermediate plutons. Most deposits are pluton-related, although some Carlin-type deposits (Zhanghai) are present in Silurian rocks.

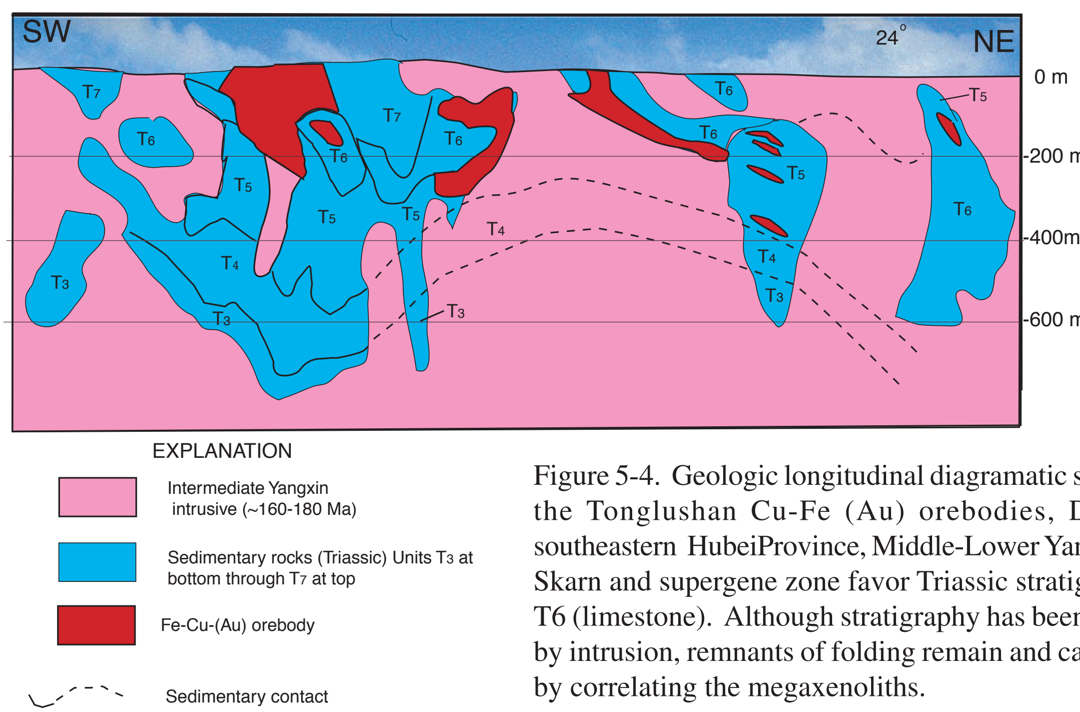


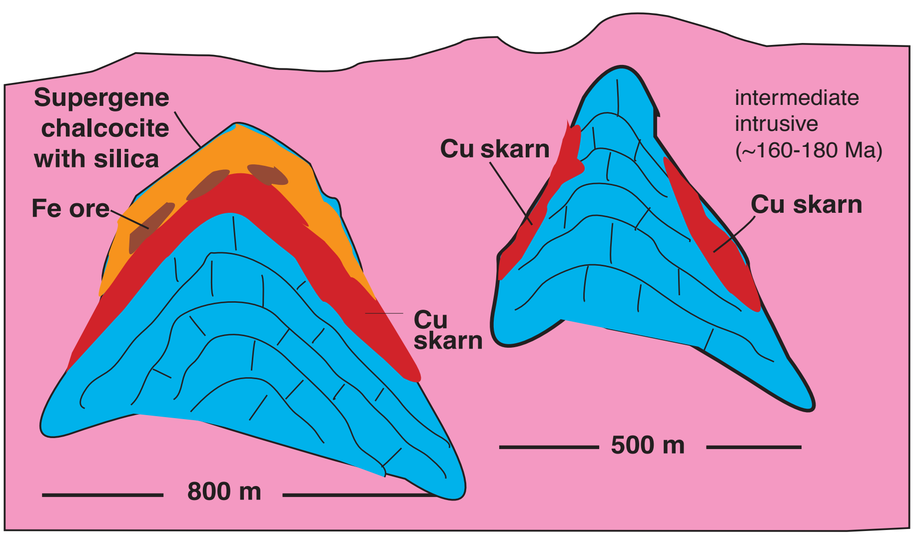
Figure 5-4. Geologic longitudinal diagramatic section through the Tonglushan Cu-Fe (Au) orebodies, Daye County, southeastern HubeiProvince, Middle-Lower Yantze River area. Skarn and supergene zone favor Triassic stratigraphc horizon T6 (limestone). Although stratigraphy has been dismembered by intrusion, remnants of folding remain and can be discerned by correlating the megaxenoliths.

and has aided exploration and mine development with the recognition of late Triassic horizons as the main ore hosts (fig. 5-4). Zoning around many of the isolated bodies of limestone typically is Cu-rich skarn near limestone that grades to Fe-rich skarn adjacent to the quartz monzonite (fig. 5-5). Supergene processes have produced local rich chalcosite, Fe-oxide and Au–rich gossan zones.

Jilongshan-Fengshandong-Lijiawan deposits

The Jilongshan-Fengshandong-Lijiawan Cu–Fe–Mo–(Au) skarn and porphyry deposits in Yangxin County represent three clustered Au–skarn and porphyry Cu–Mo deposits and peripheral polymetallic lodes around cylindrical 120 to 150 Ma plutons in folded terrane (figs. 5-3, 5-7). Mining began there in the Song Dynasty (960 to 1,279AD). The area also includes the Dongleiwan and Lijiawan porphyry prospects. The three main deposits include large Cu resources with additional reserves of Mo, Au, Ag, Ag and Rh.

The Fengshandong Cu–Mo porphyry deposit is the largest of the three deposits and has a reserve of 50 tonnes Au at 0.5 to 0.8 g/t Au, 2,000 tonnes Ag at 39 g/t Ag, 0.9 million tonnes Cu at 1.01 weight percent Cu, and 50,000 tonnes Mo at 0.02 to 0.05 weight percent Mo (see fig. 1-16, Chapter 1). The Jilongshan deposit has a reserve of 290,000 tonnes Cu at 1.5 to 1.8 weight percent Cu, 50 tonnes Au at 3.5 g/t Au, and 380 tonnes Ag at 19 g/t Ag. The Lijiawan deposit contains a reserve of 120,000 tonnes Cu grading 1.3 percent Cu, and 10 tonnes Au grading 2.5 g/t Au. The deposits are zoned from a core of central K alteration to peripheral sericite and then chlorite, and from a central Mo zone to zones of Fe, Cu, Pb–Zn, Au, and Ag toward the outside (see also, fig. 1-16, Chapter 1). All three deposits also have rich Cu skarns with >2 percent Cu grades and peripheral distal-disseminated and replacement zones of Pb, Zn, Au, and Ag.



Cu 130,000 T
Au 50 T@ 0.5-1.5 g/t

Figure 5-5. Idealized sketch of the Tonglushan Fe-Cu (Au) skarn deposit in the Daye City area, southeast Hubei Province, Middle-Lower Yangtze River area. Main orebodies are megaxenoliths or foating roof pendants of Triassic limestone (blue) in Mesozoic granitic rock (pink). Fe orebodies are common near the hypogene-supergene interface.

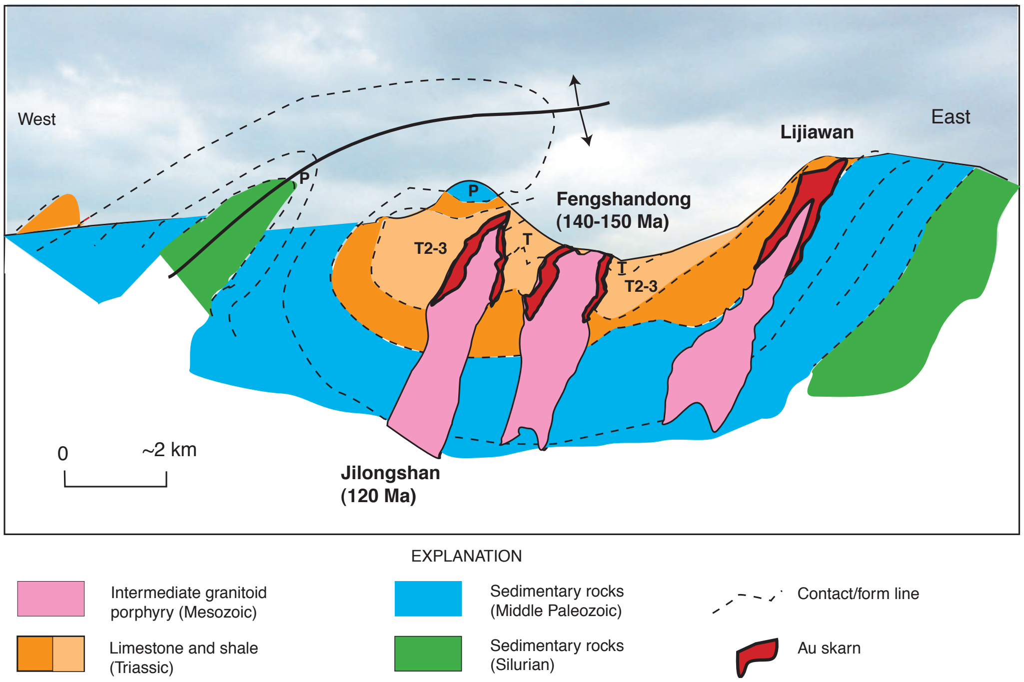


Figure 5-6. Longitudinal projection sketch of the Jilongshan Au (Cu-Fe-Mo-(Au) skarn-porphyry belt in the southeastern Hubei Province, Middle-Lower Yangtze River area. For location, see figure 5-2 and for model of deposit type, see Chapter 1, fig. 1-16.

Figure 5-7. Photographs of veiws of deposits near Daye City, Tonglushan Mining area, southeast Hubei Province., Middle-Lower Yangtze River. (*A*) Tonglongshan Fe-Cu skarn deposit (on right) and plant (on left). (*B*) JinJinzui A porphyry deposit (arrow).

JinJinzui Au porphyry deposit

The JinJinzui Au porphyry deposit is located between Daye City and the Tonglushan Mine on the northeastern margin of the Yangxin pluton and the edge of the Daye syncline (figs. 5-3, and 5-4). The deposit was discovered by Wang Yongji and Dai Dinxian of the South-Central Geological Survey, Wuhan by targeting minor gravity anomalies in the shadow of the large gravity anomaly of the Yangxin pluton (fig. 5-8). These small anomalies represented pillow-shaped, steep-plunging, 80–Ma porphyry stocks that intruded favorable Triassic limestone horizons. Skarn, however, is not well developed. Drilling, using 1–m-spaced sampling and identified a Au resource that is from 5 to 10 m inside the contact of the stock with geochemically anomalous, but sub-economic, concentrations of Cu, Ag, Zn, and Pb (fig. 5-8). Gold is present in pyritic veinlets and stockworks as 0.5– to 3–mm-size native Au grains and is associated with sericitic and quartz alteration. The JinJinzui Au porphyry deposit represents a separate Au-mineralizing event in southeastern Hubei Province that is younger than Cu–Fe skarns in the region.

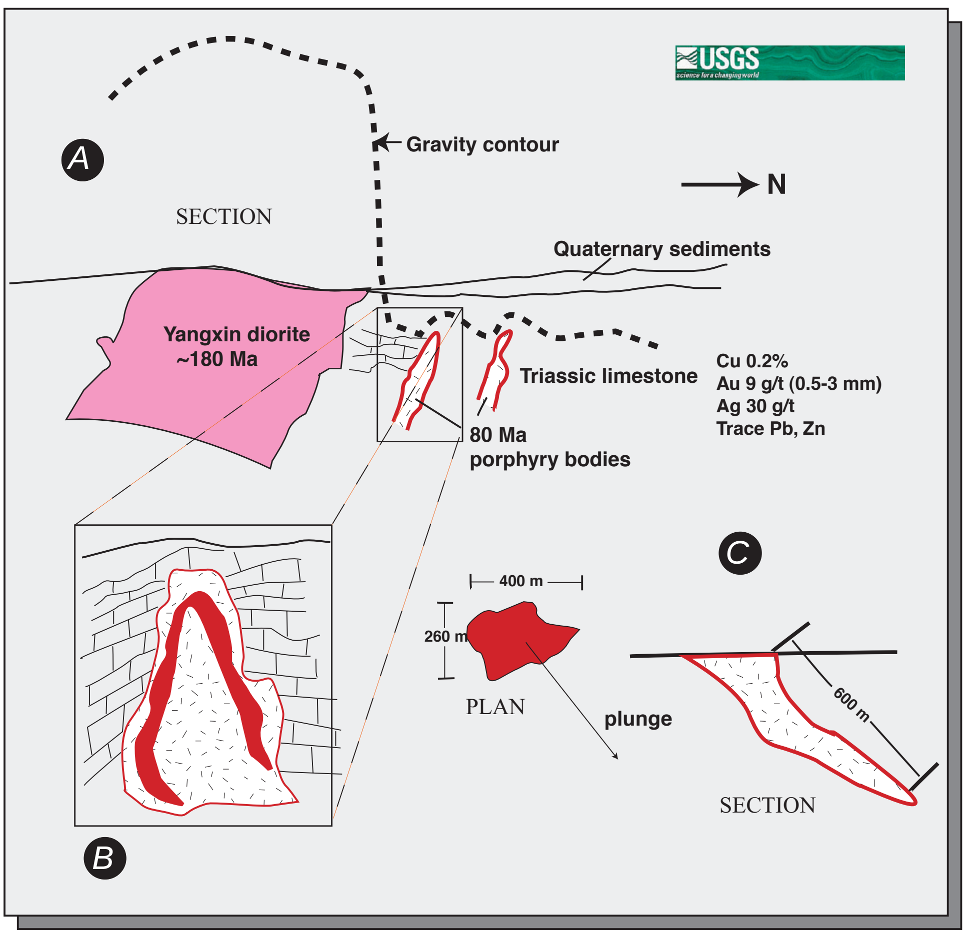


Figure 5-8. Geologic sketches of the Jinjinzui, Au porphyry deposit, Tonglushan district, HubeiProvince, Daye County, Middle-Lower Yangtze River area. (*A*) Deposit is centered on a young, cylindricalporphyry adjacent to an emayment of the Yangxin pluton. Small porphyry is burried below Quaternary lake sediments and is reflected in variations in the gravity anomaly. (*B*) Diagrammatic close up of the deposit showing major Au concentrations present in a shell on the inside of the porphyry body. (*C*) Shape of orbody is a plunging cylinder with dimensions as shown.

Xiaojiapu Au deposit

The Xiaojiapu Au deposit is located at E 114º 59’ 27” to 115º 00’ 32”, N 30º 11’ 51” to 30º 12’ 37”, about 8 km east of Huangshi City, near the town of Tienshan, Hubei Province (figs. 5-1 and 5-3) in the Middle-Lower Yangtze River area. Rocks exposed in the mine mainly are early Triassic Daye Formation (T_1d), and middle to upper Triassic Puqi Formation ($T_{2\text{-}3}p$) that includes carbonate rocks (T_1d) and argillite ($T_{2\text{-}3}p$). High-sulfur coal is mined nearby from Permian rocks. Triassic limestone also is mined in the area for cement and shipped to Huangshi City for processing. The mine district is located at the southeast end of the Tieshan anticlinorium along the southern margin of the 160 Ma Tienshan pluton (fig. 5-3).

The Xiaojiapu Au deposit consists of about 40 orebodies. Of these, 25 orebodies are present in the east part of the mine area and 15 orebodies are present in the west part of the district (fig. 5-9). About 5 million tonnes

of ore are currently (2000) in reserve. Most orebodies are 30 to 40 m long, 2 to 5 m thick and dip north or south at angles between 60 and 70º. Grade of Au ore is 2.08 to 4.41 g/t Au. The average grade is 3 g/t Au. Gold grade decreases from west to east in plan and from upper to lower parts of the orebody in vertical section from oxide ores downward into the hypogene zone.

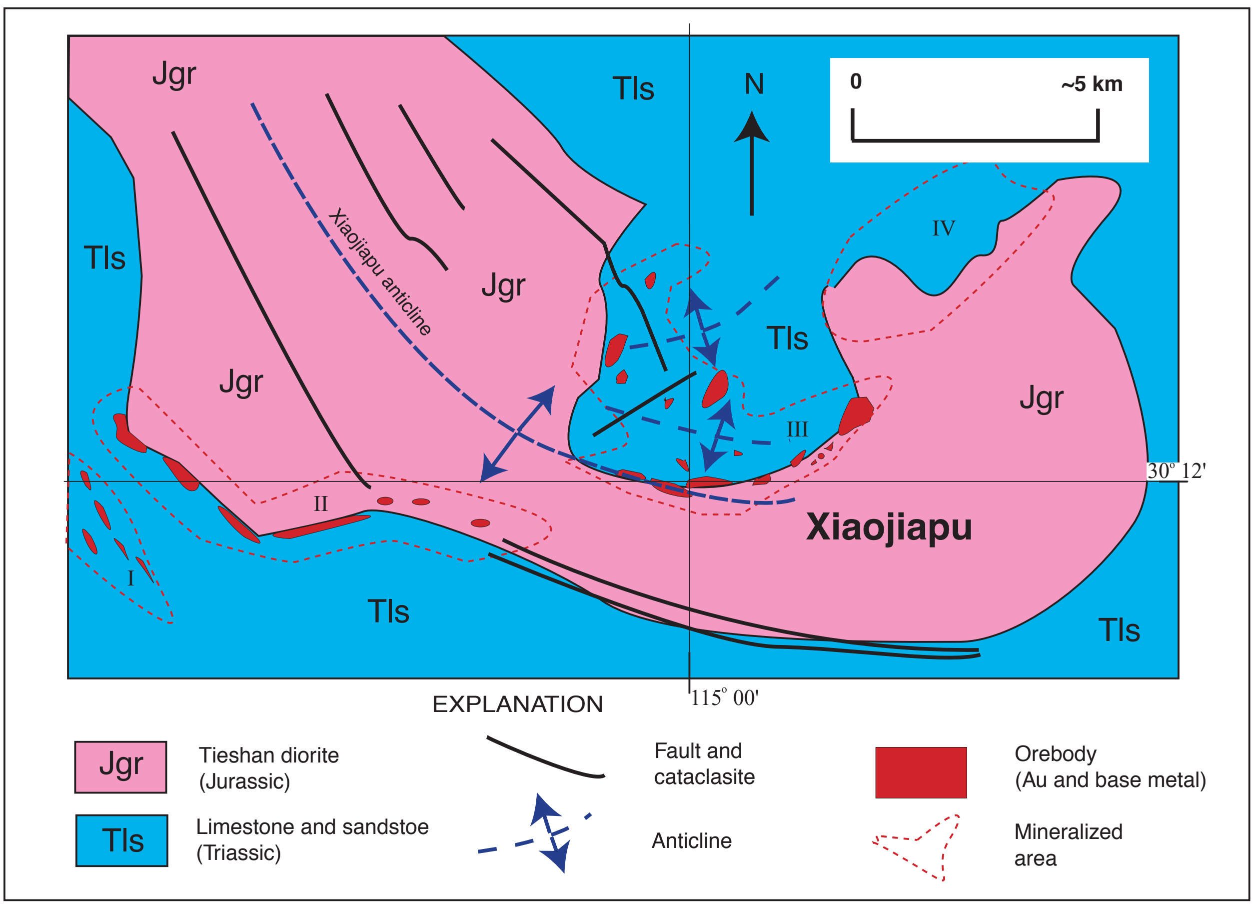


Figure 5-9. Geologic sketch map of the Xiaojiapu Au deposit area, southeastern Hubei Province, Middle-Lower Yantze River area. Goldand base metal orebodies are related to Triassic limestone hornsfels zone along the contact with the Tieshan diorite pluton. Roman indicate mining areas. Latitude and longitude are approximate.

Gold reserve is 2,429 kg Au. Silver reserve is 14.25 t (grade at 18.88 g/t Ag), and Pb ore reserve is 1,643 t Pb (grading 0.31 percent Pb). The Xiaojiapu area also is the largest Sr resource in China. The area visited in 2000 was a recently discovered deposit that included a new, 1 tonne Au resource, that is a gossanous zone approximately 8 m deep, 200 m long, and dips 30º east. Information about the Xiaojiapu Au deposit is from the 601 and 606 Teams of the Central South Geologic Exploration Bureau of MMI.

Prospecting in the Xiaojiapu Au deposit area is conducted by trenching and the opening of small shafts and adits, commonly after some drilling (fig. 5-10). Mining is by open pit methods in the oxide ores using backhoes and trucks. Since much of the ore is gossanous and oxidized, blasting is not universally used in the mine workings. The ore is crushed to about 1 cm, screened and hand loaded in approximately 5 tonne vats with a head grade of 3 to 5 g/t Au after trucking to various leach sites. Vat cycling time is about 1 week. The Au is recovered using a Zn-displacement method rather than charcoal.

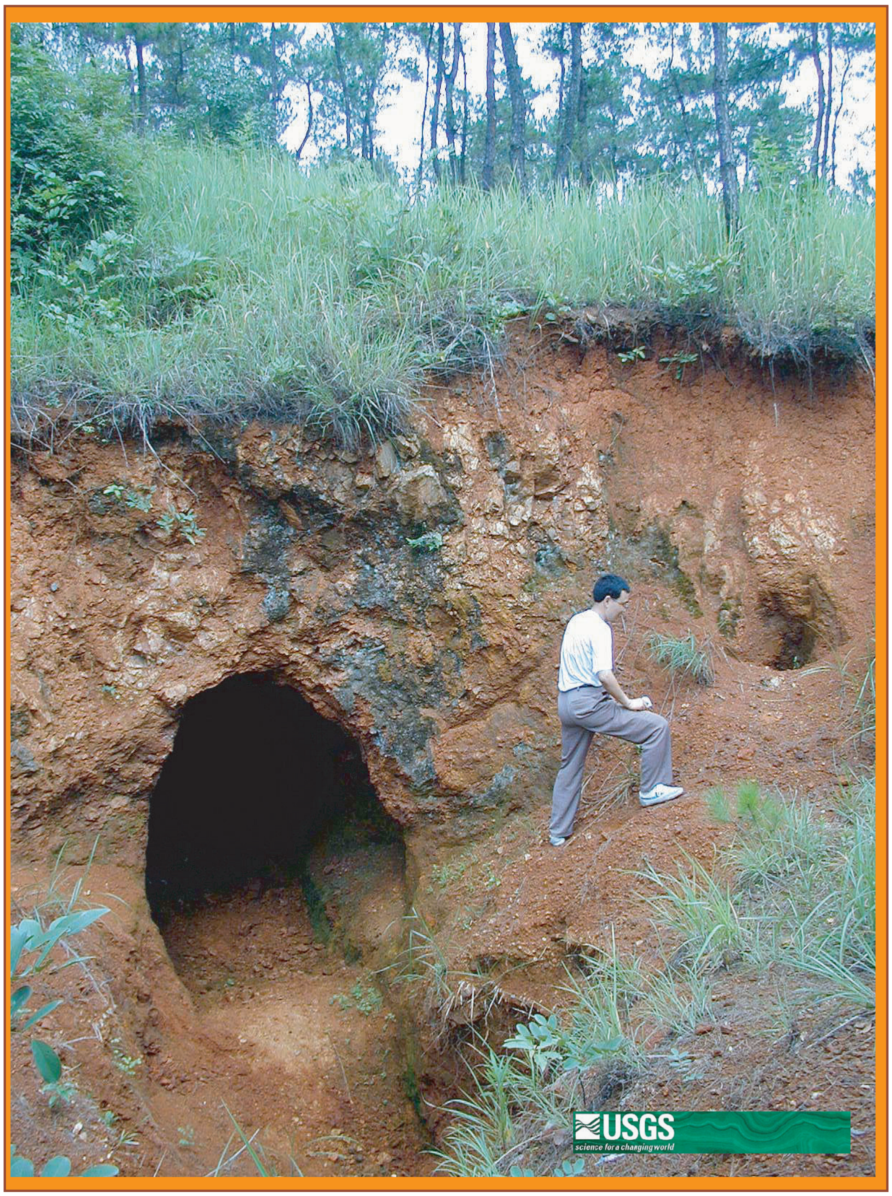


Figure 5-10. Photograph of exploration adit in the gossanous horizon at Xiaojiapu Au deposit, southeastern Hubei Province, Middle-Lower Yangtze River area.

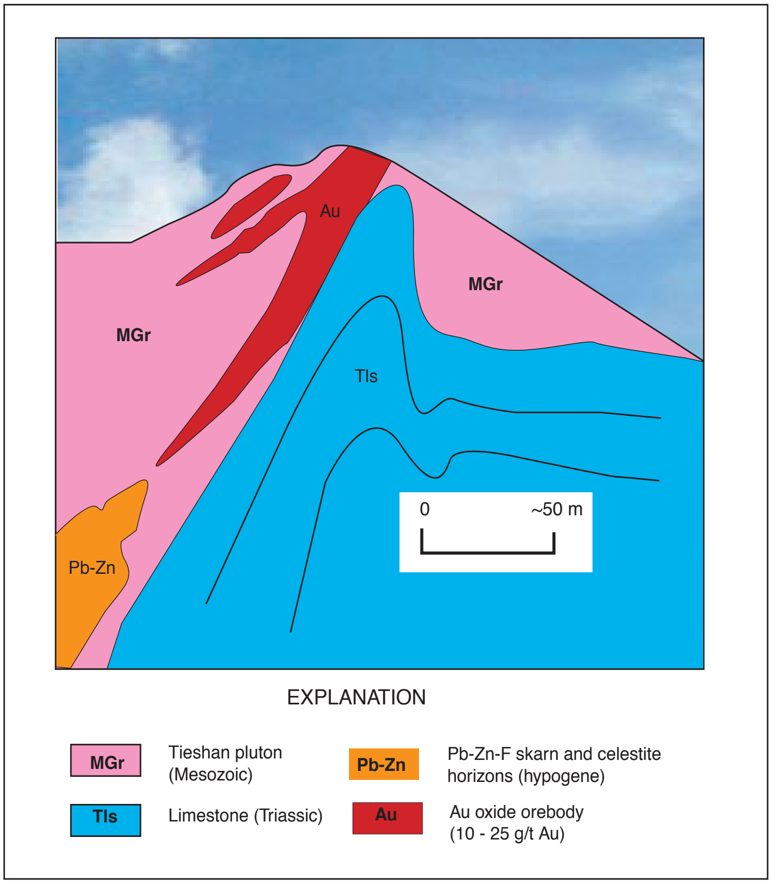


Figure 5-11. Schematic cross section showing elements of pluton-hosted ores in the Xiaojiapu Audeposit, southeast Hubei Province, Middle-Lower Yangtze River area. The upper parts of the oxideore are gossanous and clay-bearing. Anticlinal structures or limbs of folds also are importantcontrols of ore, as well as specific stratigraphic horizons in the Triassic stratigraphy. Modified from the Non Ferrous Industrial Bureau and Team 812 of the East China Geological Exploration Bureau, Tongling (see also, Wang, B.H., 1996).

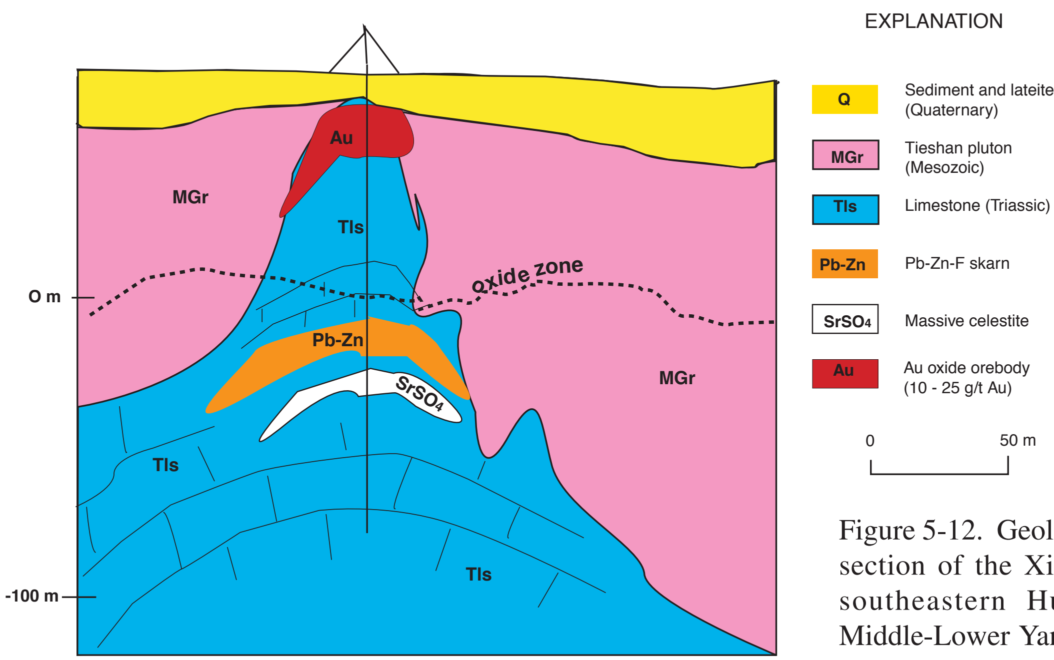


Figure 5-12. Geologic sketch cross section of the Xiaojiapu deposit, southeastern Hubei Province, Middle-Lower Yangtze River area. Gold ore is in gossanous masses near the surface. Drill holes have documented hypogene Pb-Zn-F and separate Sr ore pods that are each stratigraphically controlled at depth.

Orebodies are present along the limbs of the Xiaojiapu anticline (fig. 5-9) and are associated with or hosted in altered, fracture zones that are parallel to the anticline, and which control the morphology and location of the orebodies. Morphology of orebodies is vein-like, lenticular, and pod-like in plan and wedge- or pod-shaped in cross section, and funnel-shaped in vertical section (figs. 5-11, 5-12, and 5-13). Mineralized zones generally are stratabound lenses in specific beds of the Triassic sedimentary limestone. Gold zones typically are gossanous layers in the oxide zone (figs. 5-11, 5-12, and 5-13). Hypogene ores are present down dip or in separate layers.

Yanshanian (185 to 67 Ma) igneous rocks are widespread in a 6,000 m^2 area and specifically in a 1,300– X 3,000–m-size area around the mine. The Tienshan pluton is composed of two apophyses. Upper apophyses intrude gently dipping fracture zones between units T_1d and $T_{2-3}p$. Lower apophyses intrude along the south limb of the Xiaojiapu anticline. The apophyses are composed of porphyritic quartz diorite, medium-grained quartz diorite, porphyritic diorite,

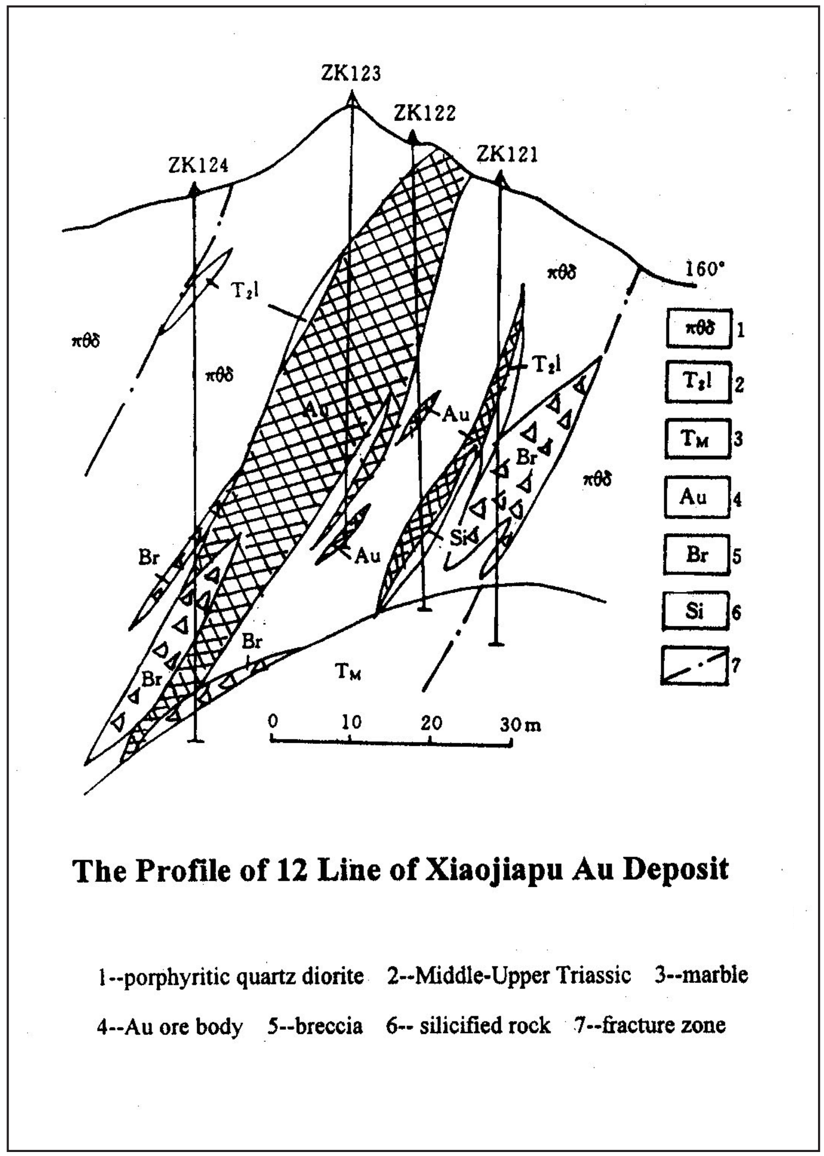


Figure 5-13. Cross section through the Xiaojiapu Au deposit, Middle-Lower Yangtze River area, southeastern Hubei Province. Modified from the 601 team of the South Central geological Exploration Bureau.

hypabyssal quartz porphyry dikes, and lamprophyre dikes. The most common igneous rock types are porphyritic quartz diorite and porphyritic diorite, which both are related to the Au ore.

Faults are widespread and divided into two groups in the Xiaojiapu mine area. One group is present along the axis of the northwest-trending, 100– to 1,000–m-long Xiaojiapu anticline and dips to the south or north at angles of 60 to 80º and contains abundant altered cataclastic rocks that define a major fault zone within the anticline (fig. 5-9). Brecciated and cataclastic porphyry, argillic siltstone, fragments of barite, and limonite-bearing Au-mineralized rock are distributed along the fault zone, which also contains local mylonite and 0.5– to 1.5–m-thick barite veins along the fault zone margins. Gold mainly is proximal to this fractured zone, along horizons of Triassic limestone, along fold zones, and along granitic contacts. Another group of 100–m- to several km-long, north-striking fractures dip east or west at angles between 90 and 65º and displace the major east-striking fracture zone. Fractures were conduits for both magma and Au-bearing ore fluid (fig. 5-13).

Hydrothermal alteration is widespread in the Xiaojiapu Au deposit area and is typified by silicification and introduction of carbonate minerals, pyrite, other sulfide minerals, fluorite, and barite. Silicification is present as two types. One type is quartz vein-networks that cut and silicify porphyritic diorite, porphyritic quartz-diorite, and argillic siltstone. The other type includes a barite-quartz association that is present as veins, lenses, pods, and irregular shapes that overprint the silicified quartz vein-networks. Zones of silicification are 100 m long and several meters to several tens of meters wide in intensely silicified areas. The silicified bodies are gray and associated with barite and pyrite, or limonite in the oxide zone, and are directly associated with Au ore. Introduction of carbonate minerals is related to development of marble and introduction and replacement of siltstone, and also to local replacement of plagioclase in quartz diorite.

Pyrite and sulfide mineral introduction has two types of expression. The first type is veinlets that crosscut igneous rocks and limestone-marble. The second type is as disseminations in the silicified rocks, especially associated with Au in the ore-bearing fractured zones. Disseminated pyrite is an important marker for prospecting for Au, Ag, Pb, and Zn (figs. 5-14 and 5-16). Barite is present as small cm– to 1–m-wide veins and veinlets that crosscut diorite. Barite is euhedral and coarse-grained and associated with quartz. Limonite development in the oxide zone as coatings and massive gossans are most commonly associated with carbonate rocks (figs. 5-10, and 5-15). Celestite is massive and white in several meters wide zones and contains local inclusions of quartz and barite (fig. 5-15). Strontium grade of these ores is 80 weight percent Sr.

Non-metallic gangue minerals in the ore are quartz, feldspar, and sericite and they make up about 81.9 volume percent of the Au ore. Metallic minerals mainly are limonite (14.36 volume percent), hematite (1.35 volume percent), rutile (0.96 volume percent) and magnetite (0.34 volume percent). Ore texture in the oxide zone is gossanous with boxwork, anhedral granular, colloform, porous, disseminated, banded, and breccia textures. Five main types of ore are present: (1) limonitic porphyritic quartz-diorite type; (2) argillic siltstone type; (3) silicified rock type; (4) general limonite type; and (5) breccia type.

Geochemically the Xiaojiapu Au deposit is anomalous in F, As, Bi, Hg, and contains highly elevated concentrations of Cu, Pb, and Zn. The ores also are characteristically high in Ag (3.75 to 56.5 g/t Ag) compared to Carlin-type Au deposits (table 5-1). These geochemical characteristics are similar to those found in pluton-related, distal disseminated Ag–Au and polymetallic replacement deposits, although the elevated Hg values have similarities to Carlin-type deposits as well. Value of $\delta^{34}S$ for sphalerite is +11 ‰ (table 5-1).

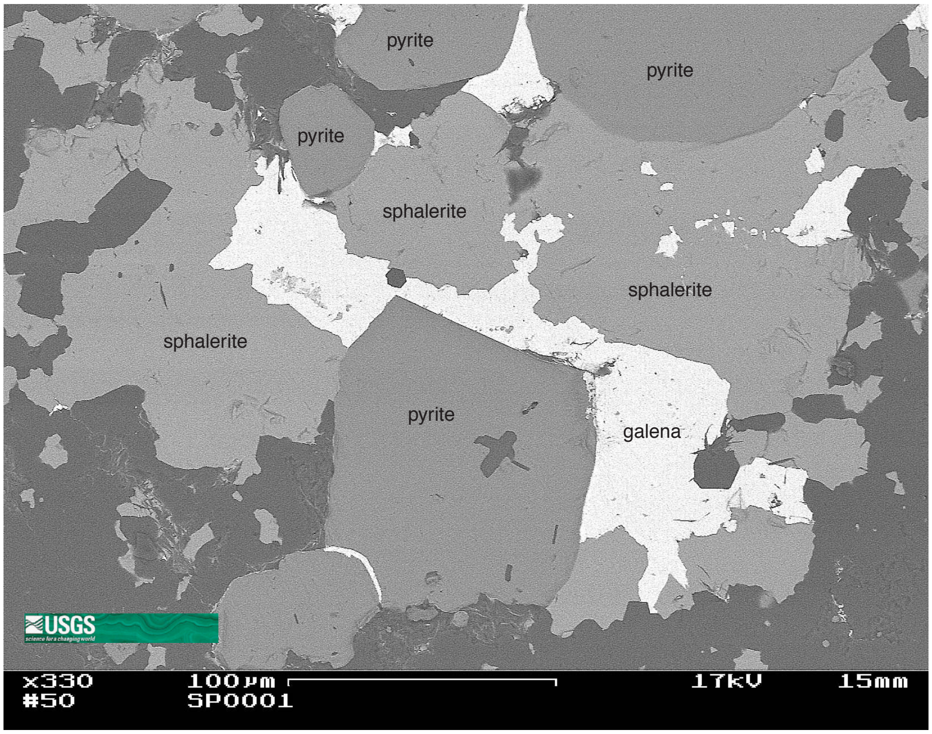


Figure 5-14. Scanning electron microscope backscatter image of sulfide ore in Xiaojiapu Au deposit, southeastern Hubei Province, mMddle-Lower Yangtze River area. Ore also contains minor chalcopyrite, barite, and flourite. Assay is Zn = 14.3 weight percent, Ag = 70.99 g/t, Pb = 1.46 weight percent, Au = 0.06 g/t.

Figure 5-15. Photograph of gossanous rubble crop on lateritic soil of the Xiaojiapu Au deposit, southeastern Hubei Province, Middle-Lower Yangtze River area.

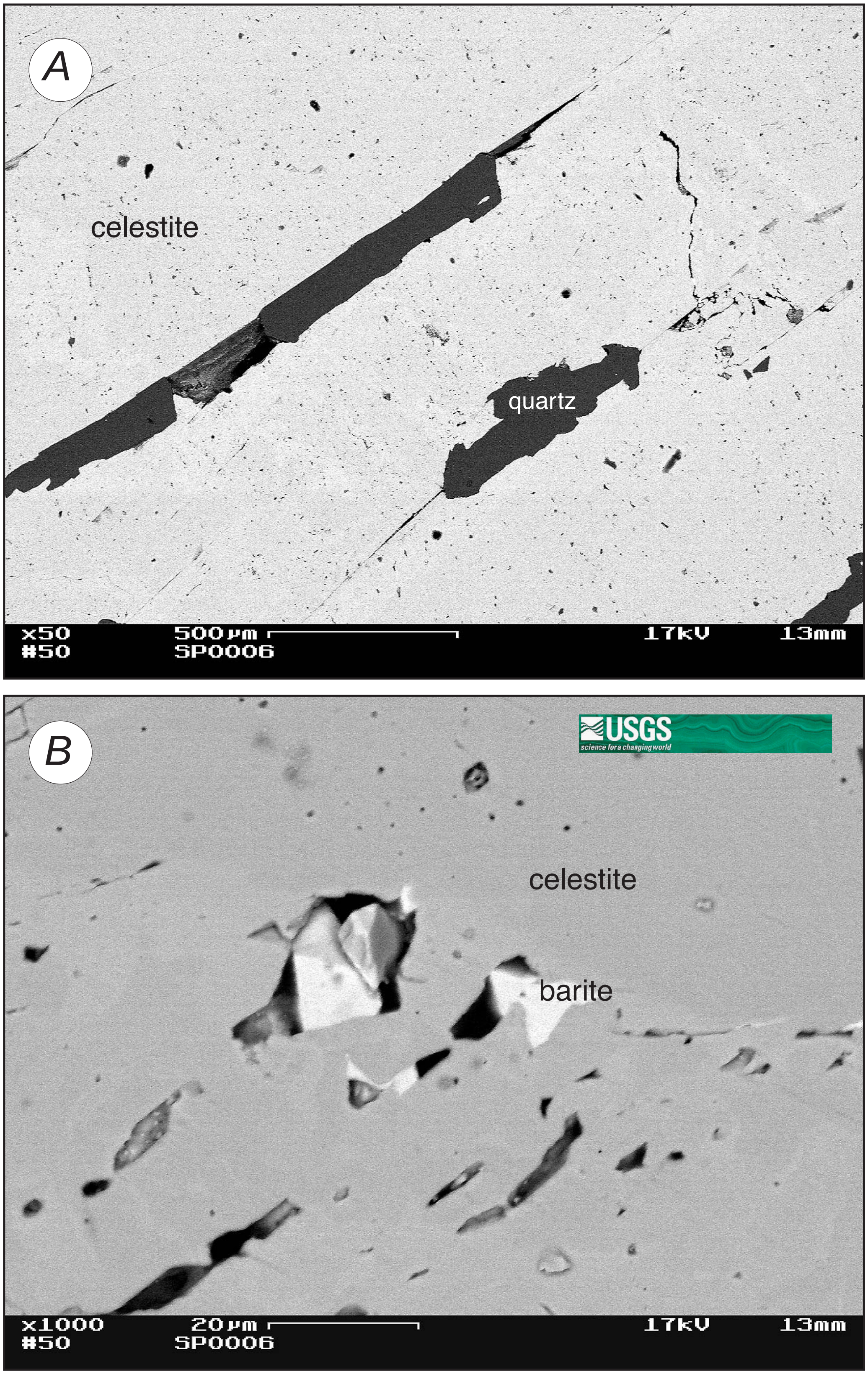


Figure 5-16. Scanning electron microscope image of massive celestite (SrSO4), showing inclusions of quartz (*A*) and barite (*B*). Xiaojiapu Au deposit, southeasternHubei Province, Middle-Lower Yangtze River area.

Zhanghai Au deposit

The Zhanghai Au deposit is located at E. 114° 52’ 49” to ~114° 54’ 18”” and N. 29° 54’ 51” to ~29° 55’ 30”” about 24 km to the southwest of Daye City, at the village of Zhanghai, Hubei Province, Middle-Lower Yangtze River area southwest of the Yinzu pluton (figs. 5-1, 5-3, and 5-17). The Zhanghai Au deposit consists of four orebodies. Orebodies mainly are controlled by interformational fractural zones and are stratabound and lens-like and conform to the sedimentary beds or to phyllitic surfaces, and dip gently at angles between 35° and ~15°. The Au–mineralized zone is 240 m long and 80 m wide. Gold grade is 2 to 3 g/t Au. The deposit is a small Au deposit and contains about 15 tonnes Au. An extension of the mineralized zone lies about 0.5 km west in the hills west of Zhanghai Village. Information about the Zhanghai Au deposit is from Team 603 of the Central South Geological Exploration Bureau of MMI.

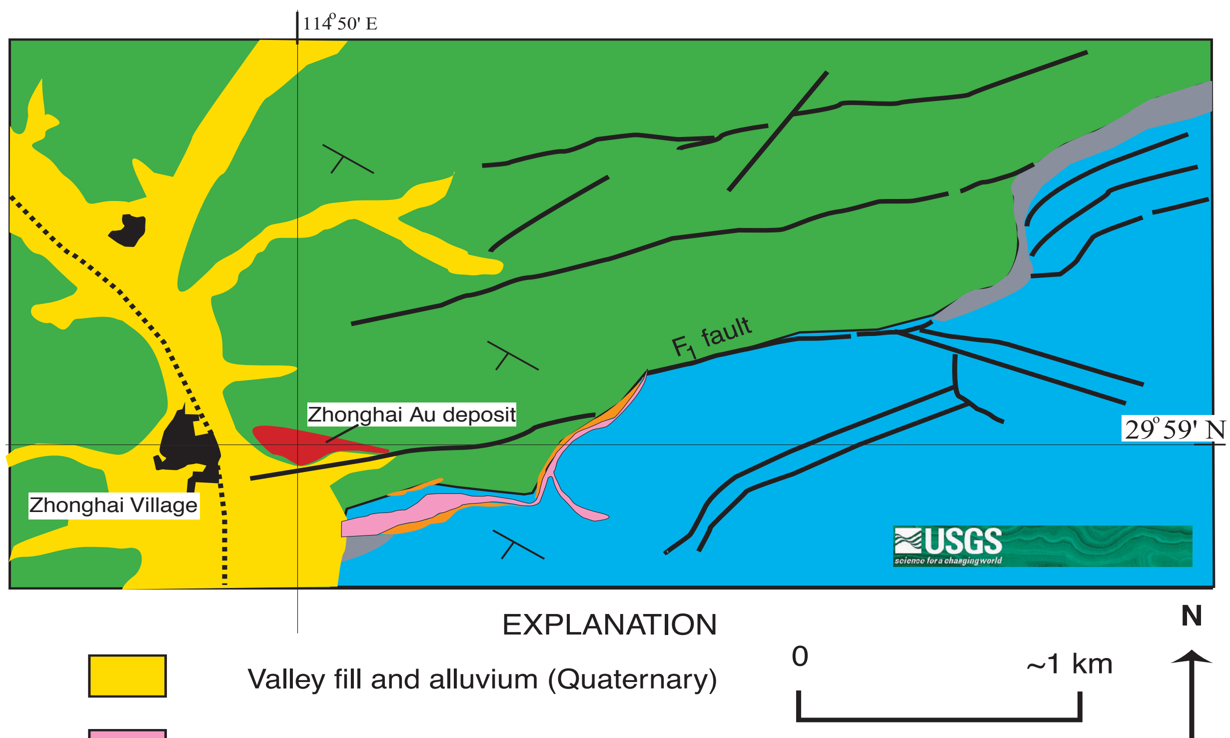


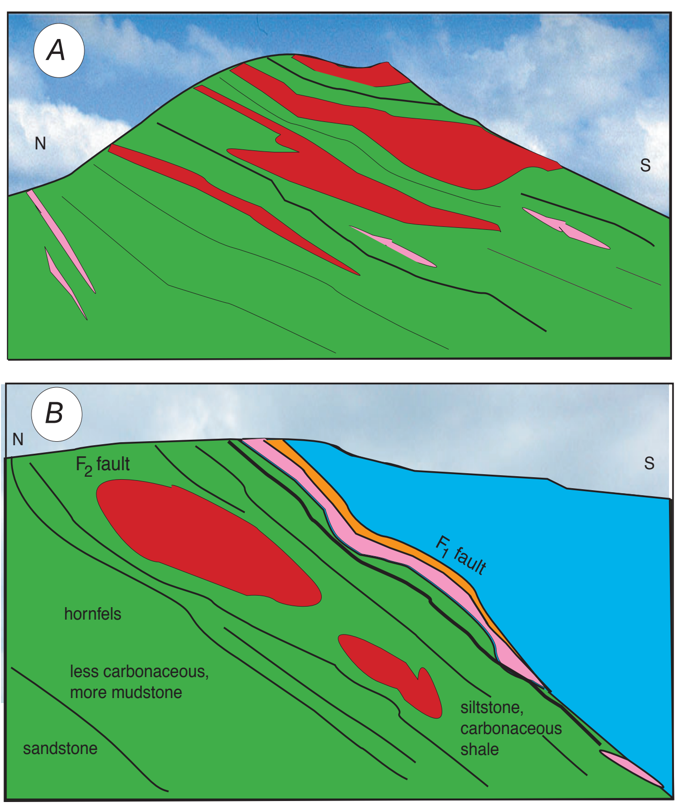
Figure 5-17. Geologic map of the Zhanghai Au deposit area, southeastern Hubei Province, Middle-Lower Yangtze River. Deposit is hosted in black carbonaceous Silurian slate and shale. Gossan and intrusive appear to be part of a separate metallogenic event. Modified from 603 Team South Central Geological Exploration Bureau.

The Zhanghai Au deposit is developed by a small open pit mine and by adits that have been designed using information from drilling, surface geological mapping, trenching, and geochemical sampling (fig. 5-18). Mining is conducted by hand loading of small tracker-pulled wagons. Oxide ore is hauled to vats and leached in separate vat units by family-sized groups from the Zhanghai Village (fig. 5-19).

Strata exposed around the mine are the Lower Silurian Gaojiabian Formation (S_1g), the Middle Carboniferous Huanglong Formation (C_2h), and the Lower Permian Maokou (P_1m) and Qixia (P_1q) Formations, and the Lower Triassic Daye Formation (T_1d). The Gaojiabian Formation hosts Au orebodies in south-dipping, phyllitic, yellow-green colored, thin- to medium-bedded, fine-grained sandstone, argillaceous siltstone, yellow- to green- to black-colored and gray- to green-colored arenaceous shale, silty shale, and gray-colored black carbonaceous-silty shale. Gold ore mainly is present as stratabound lenses hosted in horizons of carbonaceous silty phyllitic shale (fig. 5-20).

Figure 5-18. Photographs of the Zhanghai Au deposit mine area, southeastern Hubei Province, Middle-Lower Yangtze River area. (*A*) View looking northeast showing mine, vat leaching and dump areas and Silurian-Permian contact (white-dotted line). Arrow shows small mine working on gossan along diorite dike. (*B*) West side of open pit mine showing supergene-hypogene contact. (*C*) Truck haulage and hand-picking of oxide ore for vat leach operations. (*D*) Mine crew manning generator and pump.

Figure 5-19. Photographs of vat-leaching operations by local villagers at the ZhanghaiAu deposit, southeastern Hubei Province, Middle-Lower Yangtze River area. (*A*) Lookingwest with Zhanghai village in background. (*B*) Full vat and operations hut.



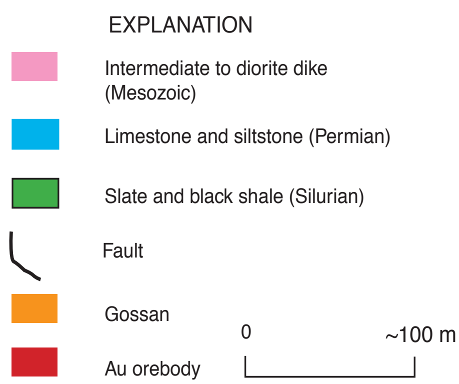


Figure 5-20. Diagrammatic sections through the Zhanghai Au deposit, southeastern Hubei Province, Middle-Lower Yangtze River area. The deposit is stratabond and disseminated in carbonaceous black slate and shale. (*A*) multiple orebodies and multiple sill-like bodies. (*B*) Main orebody with Permian hanging wall sedimentary rocks. Dike and gossan are likely not related to the main Zhanghai Au deposit.

Structurally, the Zhanghai Au mine area is dominated by a syncline where Au is present along the north limb of the syncline in the Gaojiabian Formation (S_1g). Several interformational, conformable faults, such as F_1 and F_2 in the mine area, are parallel to the stratabound ore zones (figs. 5-17 and 5-21). The 1,800–m-long, east-northeast-striking F_1 fault is present along the contact between Silurian and Carboniferous rocks and dips south-southeast (fig. 5-19*B*). The F_1 fault is a cataclastic zone in which diorite dikes have been intruded (figs. 5-17 and 5-19). Gossan also locally is present in the hanging wall and foot wall of the diorite along this fault zone, but is not related to the Au ore (figs. 5-17 and 5-18*A*). The 750–m-long F_2 fault is an oblique thrust present along the contact between the Silurian Gaojiabin and Fentou Formations and is filled with microcrystalline pyrite-bearing quartz veinlets and hosts the No.1 orebody (figs. 5-22 and 5-23).

No large magmatic bodies are exposed within the mine district. Only diorite dikes are present in the interformational fractural zones. The Yinzu intrusive (fig. 5-3) has thermally metamorphosed some of the rocks to marble and K–feldspar-rich hornfels.

Alteration directly related to Au is sericitic alteration and silicification along the mineralized bedding-conformable fracture zones. Supergene alteration consists of limonite and jarosite. Millimeter-scale quartz veinlets and local brecciation are common in the ore (fig. 5-23). The ore mainly is present as euhedral, microgranular and replacement textures and as

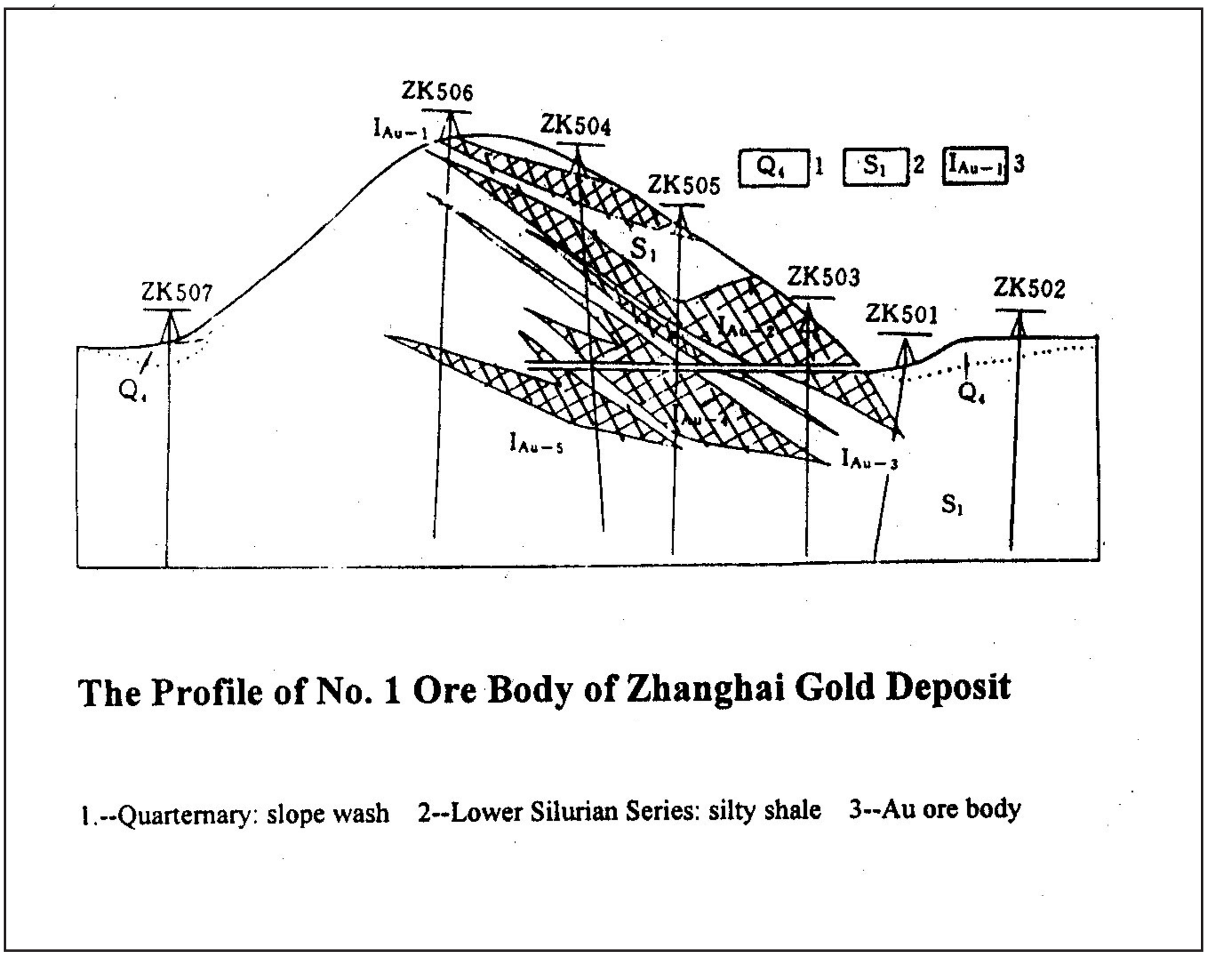


Figure 5-21. Cross section through the No. 1 Orebody of the Zhanghai Au deposit, Middle-LowerYangtze River area, southeastern Hubei Province. Adapted from the 603 Team of the South-Central Geological Exploration Bureau.

Figure 5-22. Photograph looking west toward the village of Zhanghai, near the Zhanghai Au deposit south Hubei Province, Middle-Lower Yangtze River area. The slot in the foreground is the west-striking F2 fault that is present in the orebody. The blacker rocks are carbonaceous pyritic slate, which is the host rock for Au ore.

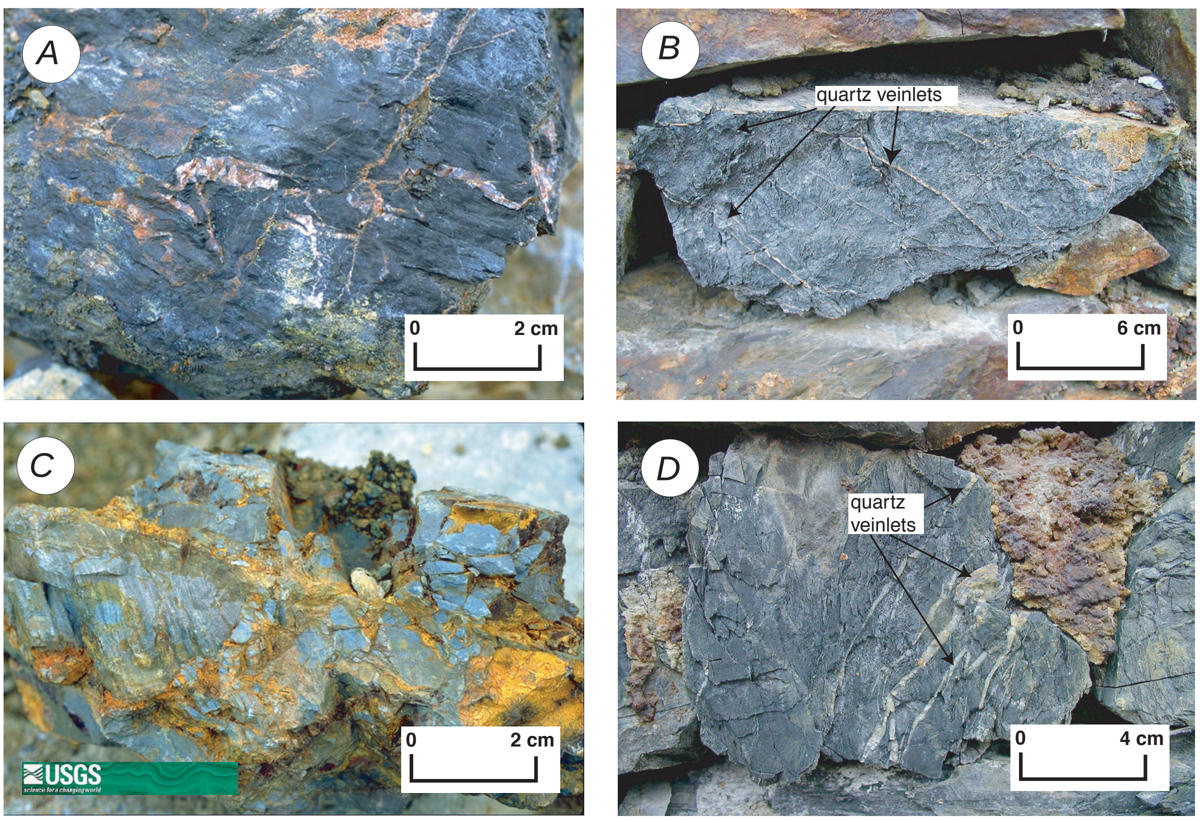


Figure 5-23. Photographs of hypogene ores in the Zhanghai Au deposit, southeastern Hubei Province, Middle-Lower Yangtze River area. (*A*) Black tectonized slate with secondary Mn(?)-rich veinlets. (*B*) Gray tectonite with disseminated As-rich pyrite and mm-scale quartz veinlets. (*C*) Veinlets of limonite in breccia ore from near the supergene-hypogene contact. (*D*) Quartz veinlets in black slate. Quartz veinlets commonly are indications of high Au contents.

disseminated, banded microlayers along veinlet-networks. Textures of sulfide minerals, especially pyrite with As–rich outer zones of arsenopyrite, are similar to those present in Carlin-type Au deposits. Pyrite is the main ore mineral in the primary ore; limonite and jarosite carry Au in the oxide zone (fig. 5-24*A*).

Pyrite typically is disseminated in the silicified host rock and locally is present as intergrowths of pyrite and rutile (fig. 5-24*B*), which are similar to intergrowths of these minerals in the Carlin-type Betze Au deposit in Nevada (Peters and others, 1998, 2000). Arsenopyrite and As–rich pyrite also is present as 100–µm-sized mottled grains that are intergrown with quartz and also are present as rims and growths on pyrite (fig. 5-24*D*, 5-25). These minerals and textures, as well as the local presence of apatite, Co–Ni–As sulfide minerals, and Hg–rich pyrite (fig. 5-26) also are typical of many Carlin-type Au deposits in Nevada (Peters and others, 1998, 2000) and in the Dian-Qian-Gui and Qinling fold belt area, China (see also, Chapters 3 and 4).

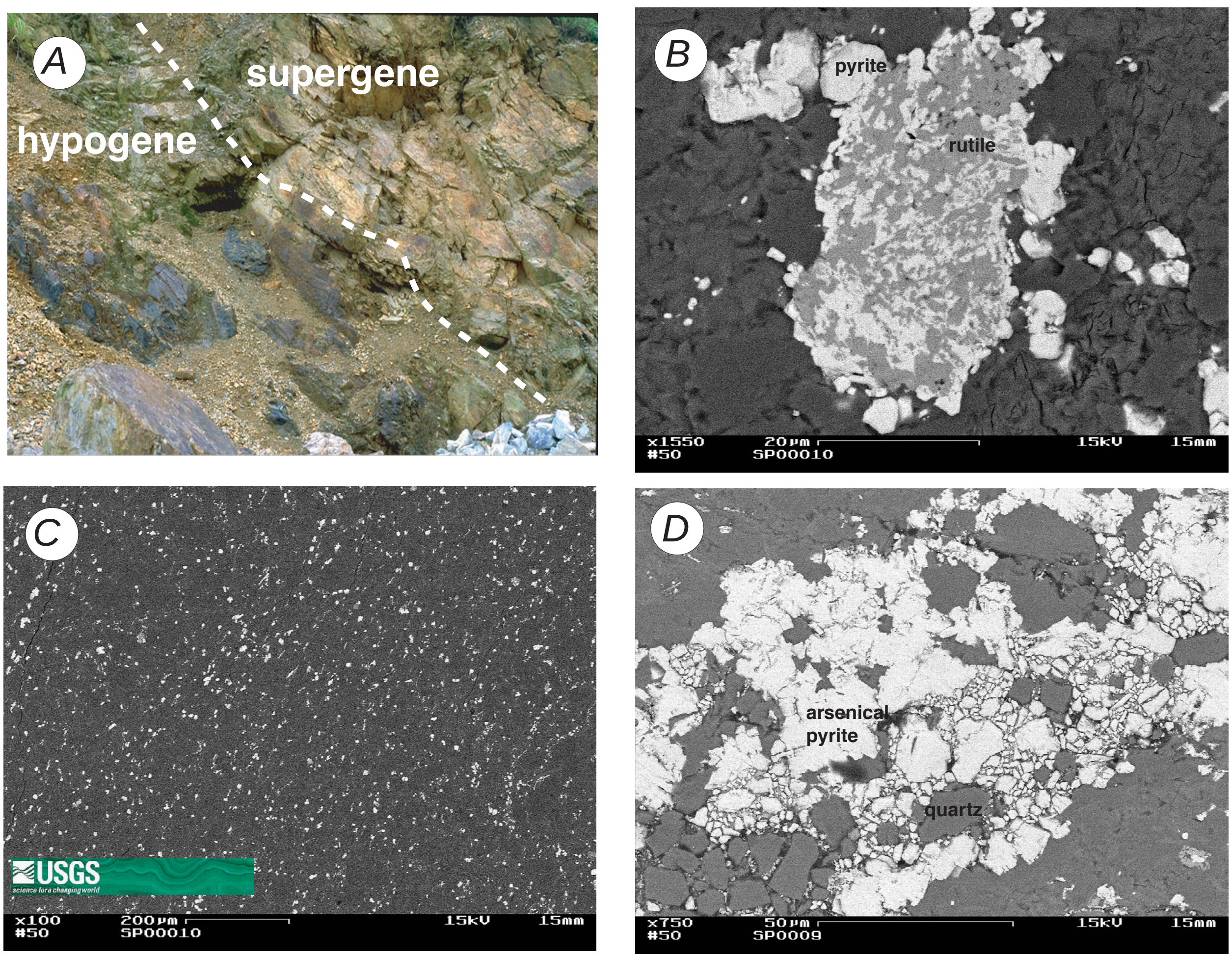


Figure 5-24. Photographs of typical ore textures and minerals in the Zhanghai Au deposit, southeastern Hubei Province, Middle-Lower Yangtze River area. (*A*) High wall on northeast side of main pit showing supergene-hypogene contact along bedding planes. Dark rock beneath is typical ore color. (*B*) Scanning electron microscope back scatter image of intergrown pyrite and rutile. (*C*) Scanning electron microscope back scatter image of disseminated locally As-rich pyrite disseminated in black slate. Note circular shape in the southeast quadrant of image. (*D*) Scanning electron microscope back scatter image of arsenical pyrite intergrown in quartz.

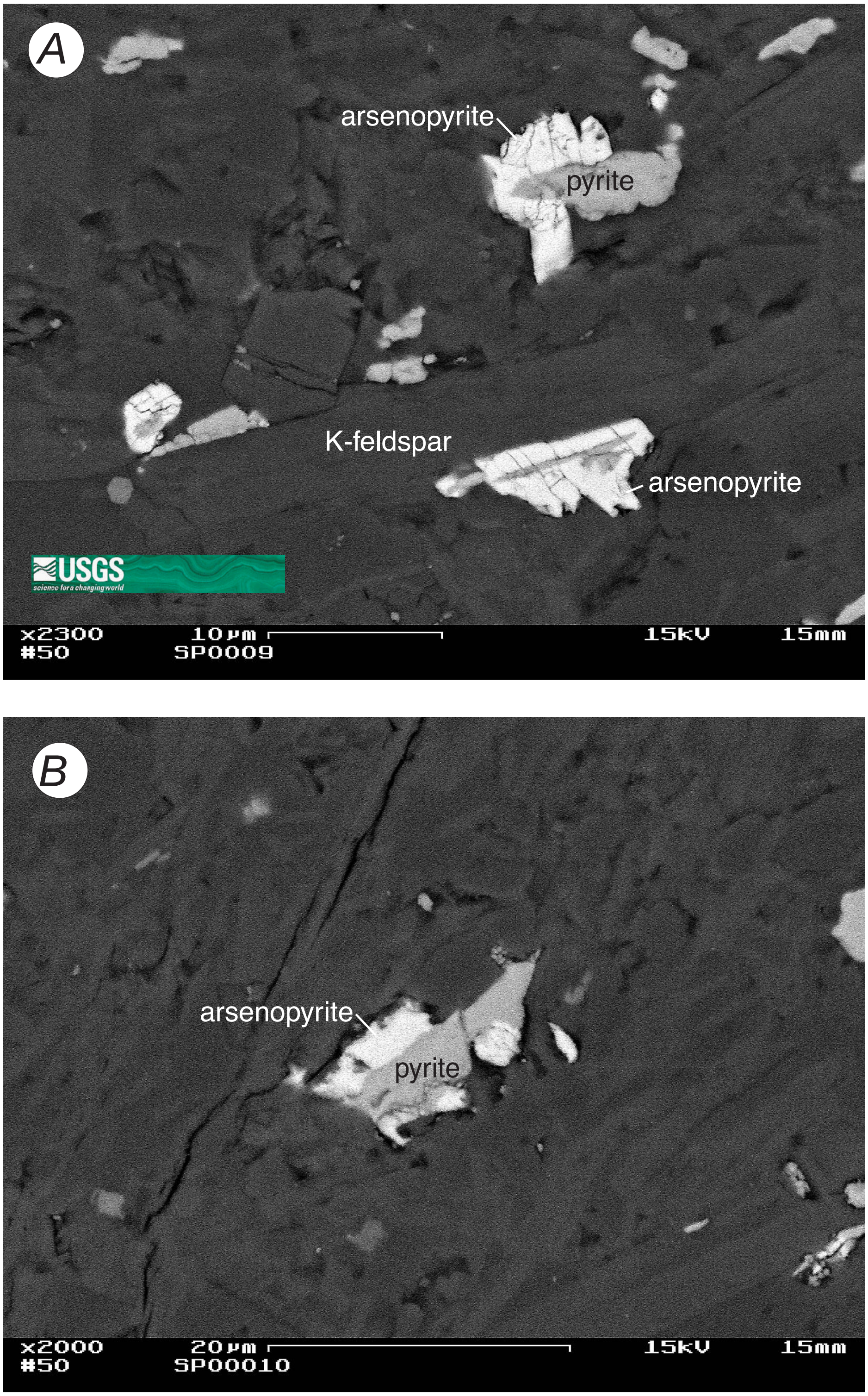


Figure 5-25. Scanning electron microscope backscatter images of arsenopyrite growths and rims on pyrite from Zhanghai Au deposit, southeastern Hubei Province, Middle-Lower Yangtze River area, hosted in carbonaceous phyllite. (*A*) Multiple grains. (*B*) Single grain.

Gold minerals are dominated by super microscopic native Au. Gold mainly is present in four different associations: (1) inclusion Au (76.28 volume percent); (2) intergrown Au with sulfide minerals (14.37 volume percent); (3) absorbed Au on silicate or sulfide minerals (8.39 volume percent); and (4) free Au (0.96 volume percent). Carriers of Au are pyrite (78.67 volume percent), sericite-mica (9.58 volume percent), carbonaceous material and organisms (8.39 volume percent).

Geochemically, the Zhanghai Au deposit ores contain anomalous or moderately elevated values of F (1,300 to 2,600 ppm), As (276 to 700 ppm), W (25 to 300 ppm), Hg (200 to 400 ppm), Ni (17 to 25 ppm), Tl (10 to 22 ppm), and Co, Cu, Pb, and Zn (Appendix IV). The values of these elements are similar to geochemical contents of Carlin-type Au deposits in the Qinling fold belt and Dian-Qian-Gui areas and in Nevada and have geochemical signatures that are distinct from the pluton-related deposits in the southeastern Hubei and Anhui areas in the Middle-Lower Yangtze River area (Appendix IV). The concentrations of Ni and As are reflected in the mineralogy of the ores shown in figures 5-25 and 5-26.

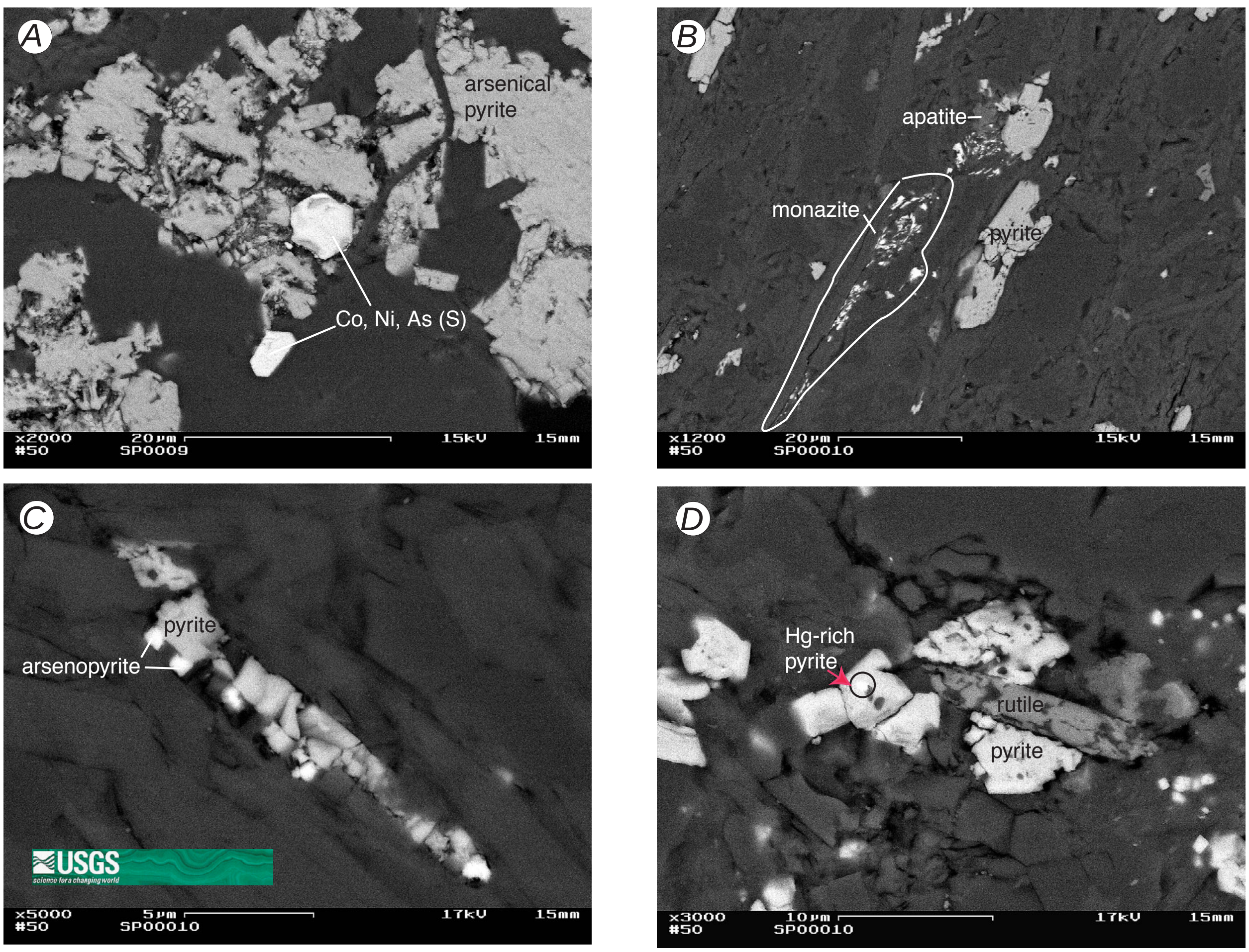


Figure 5-26. Scanning electronic microscope back scatter images of trace minerals from the Zhanghai Au deposit, southeast Hubei Province, Middle-Lower Yangtze River area. Host rock is carbonaceous phyllite. (*A*) Co, Ni, and As sulfide mineral in arsenical pyrite cluster. (*B*) Monazite and apatite with pyrite. (*C*) Arsenopyrite and pyrite. (*D*) Hg-rich zone in pyrite and rutile with pyrite. These minerals are similar to those found in Carlin-type deposits.

Shewushan red earth Au deposit

The Shewushan Au deposit is situated in low country on a hill in Jiayu County, Hubei Province, 20 km in a southwest direction from the Jiayu County Town at E 113˚ 41’ 15” and N. 29˚ 55’ 20”, south of the Yangtze River (figs. 5-1, and 5-27). The Shewushan Au orebody is the largest red earth Au deposit in China and is hosted in a well-developed lateritic profile that consists of near-horizontal stratabound layers and large, supergene, conformable Au ore lenses at depths of 0 to 45 m. Genesis of the orebody and stratigraphic identification are obscured by local, pre-weathering, intense shearing, cataclasis, and by the laterite profile. The main orebody is 1,520 m long, 200 to 300 m wide, and 10 to 20 m thick (maximum, 44 m), dipping east and west at angles of 10˚ to 20˚. Gold grade of lateritic ore is 1.5 to 5 g/t Au. Hypogene cataclastic limestone samples from drill holes show maximum Au values of 1 to 3 g/t Au. Gold extraction recovery from cyanide heap-leaching operations is 88 percent to ~99 percent. Information about the deposit is from unpublished data by Wu Yianzhi, Chen Genwen, and Fan Xiren of the South-Central University of Ministry of Metallurgical Industry and from the Fourth Geologic Team of Hubei Province of Ministry of Geology and Mineral Resources.

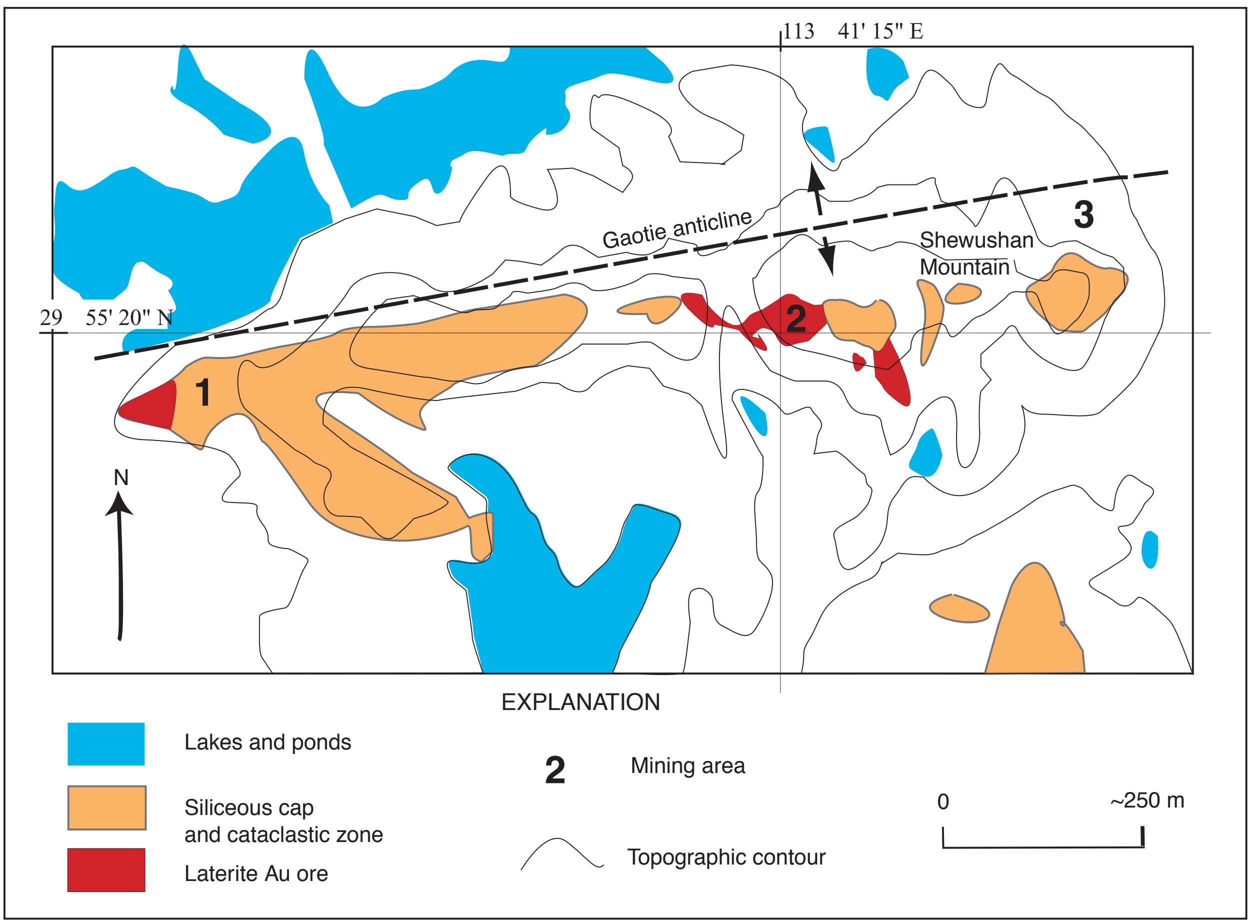


Figure 5-27. Geologic sketch map of Shewushan Au deposit area, southeastern Hubei Province, Middle-Lower Yangtze River area. Modified from Wu Yianzhi, Chen Genwen, and Fan Xiren of the South-Central University of Ministry of Metallurgaical Industry and from the Fourth Geologic Team, Hubei Province of Ministry of Geology and Mineral Resources. Latitude and longitude areapproximate.

The Shewushan Au deposit was discovered in about 1988 from an 8–km^2 anomalous zone identified by a regional stream geochemical survey that generated concentrations of 7 ppb Au, 144 ppb Hg, and elevated Sb contents. This anomaly was followed up by soil and rock sampling that defined a 1,750–m-long by 400–m-wide zone of 100 ppb Au contents with auxiliary high contents of As, Sb, and Mo. Trenching was conducted along this area and defined a Au–mineralized, 320–m-long, 22– to 43–m-wide zone with Au grade of 2.6 g/t Au (highest 7.47 g/t Au). Drilling commenced in 1989 and identified two orebodies, the first 0.2 to 6.95 m deep, 6.74 m thick, grading 2.6 g/t Au and the second 14.1 to 37.5 m deep, 23.45 m thick, grading 6.88 g/t Au wit the heist values of 19.19 g/t Au. These two zones roughly coincide with Mining Areas Nos. 1 and 2 (figs. 5-27 and 5-28).

The two Shewushan orebodies have been mined since 1994, one by the local Jiayu County and Hubei Gold Bureau Joint Venture, and the other by the Fourth Geologic Team of Hubei Province of MGMR. Total production from the area has been about 400 kg Au per year, or about 30 kg Au per month, at about 1,600 tonnes ore per day from several open pit operations (figs. 5-28 and 5-29). Mining is conducted by backhoe excavation that feeds dump trucks. There is limited blasting due to the soft nature of the laterite host (fig. 5-29). Ore is hauled to a hopper and agglomerated and fed by conveyor belt to cyanide heap-leach pads (figs. 5-30 and 5-31). Previous recovery methods also employed 10– to 30–tonne-sized heap-leach vats at Mining Area No. 2

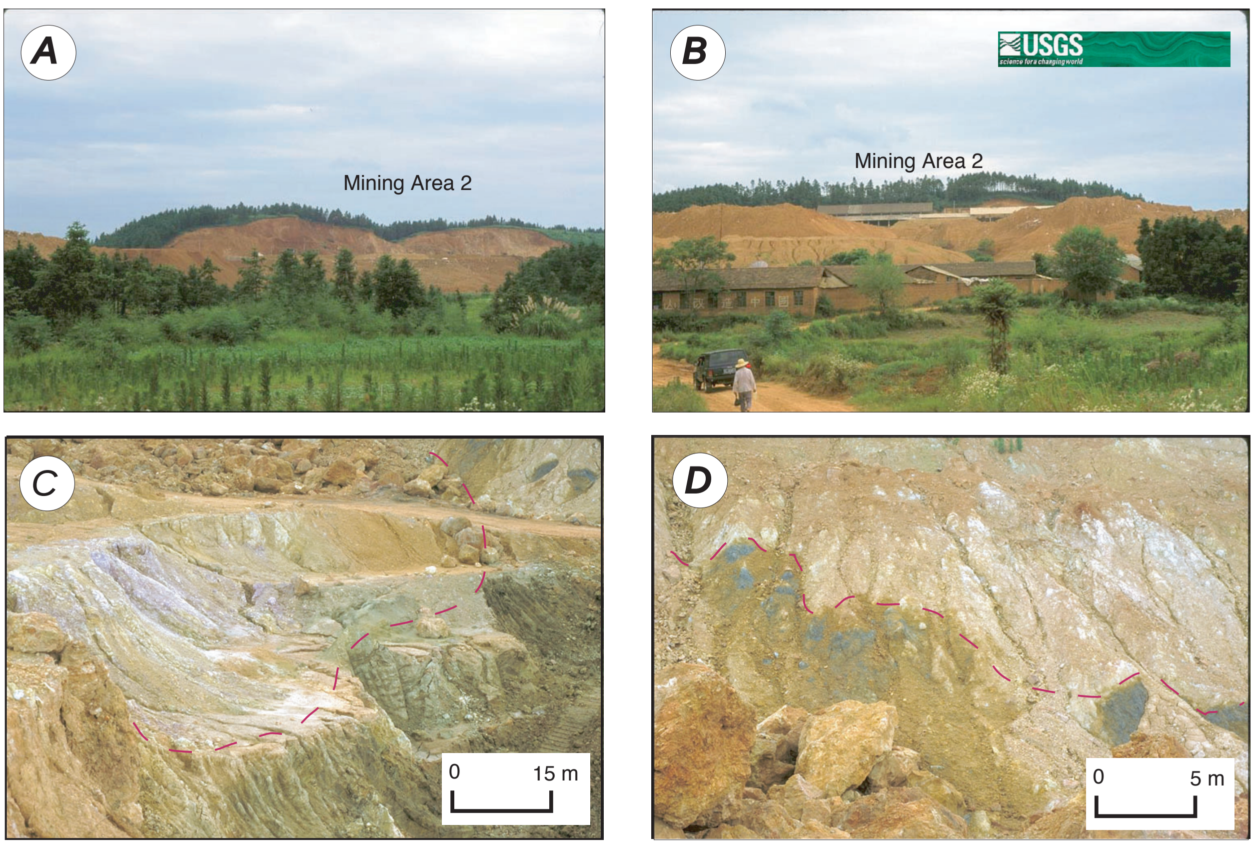


Figure 5-28. Photographs of Shewushan Au deposit area showing color patterns in lateritic rocks, southeastern Hubei Province, Middle-Lower Yangtze River area. (*A*) Panoramic view of south part of Shewushan hill on south side showing open pit mine. (*B*) View of south side of Shewushan hill showing mine waste dumps and vat processing facilities (near horizon). Mining Area 1. (*C*) Layered laterite profile on open pit, showing color contrasts. (*D*) Closeup view of color contrast on mine bench, Mining Area 1.

Figure 5-29. Photographs of mining activities in the Shewushan Au deposit, southeastern Hubei Province, Middle-Lower Yangtze River area. (*A*) Back-hoe loading at bottom of open pit. Profile of laterite in background. Mining area 1. (*B*) Multiple truck loading and digging of soft saprolite. Mining area 1. (*C*) Profile of laterite zone and trucks. (*D*) Looking north on east side of deposit in east Mining Area 2. Dark line shows intraformational fault.

Figure 5-30. Hopper and conveyor system and snake head outcrop at Shewushan Au deposit, southeastern Hubei Province, Middle-Lower YangtzeRiver area. Snake head outcrop is part of silicified cataclastic cap zone on deposit. Conveyor system feed heap-leach dumps. East Mining Area 2.

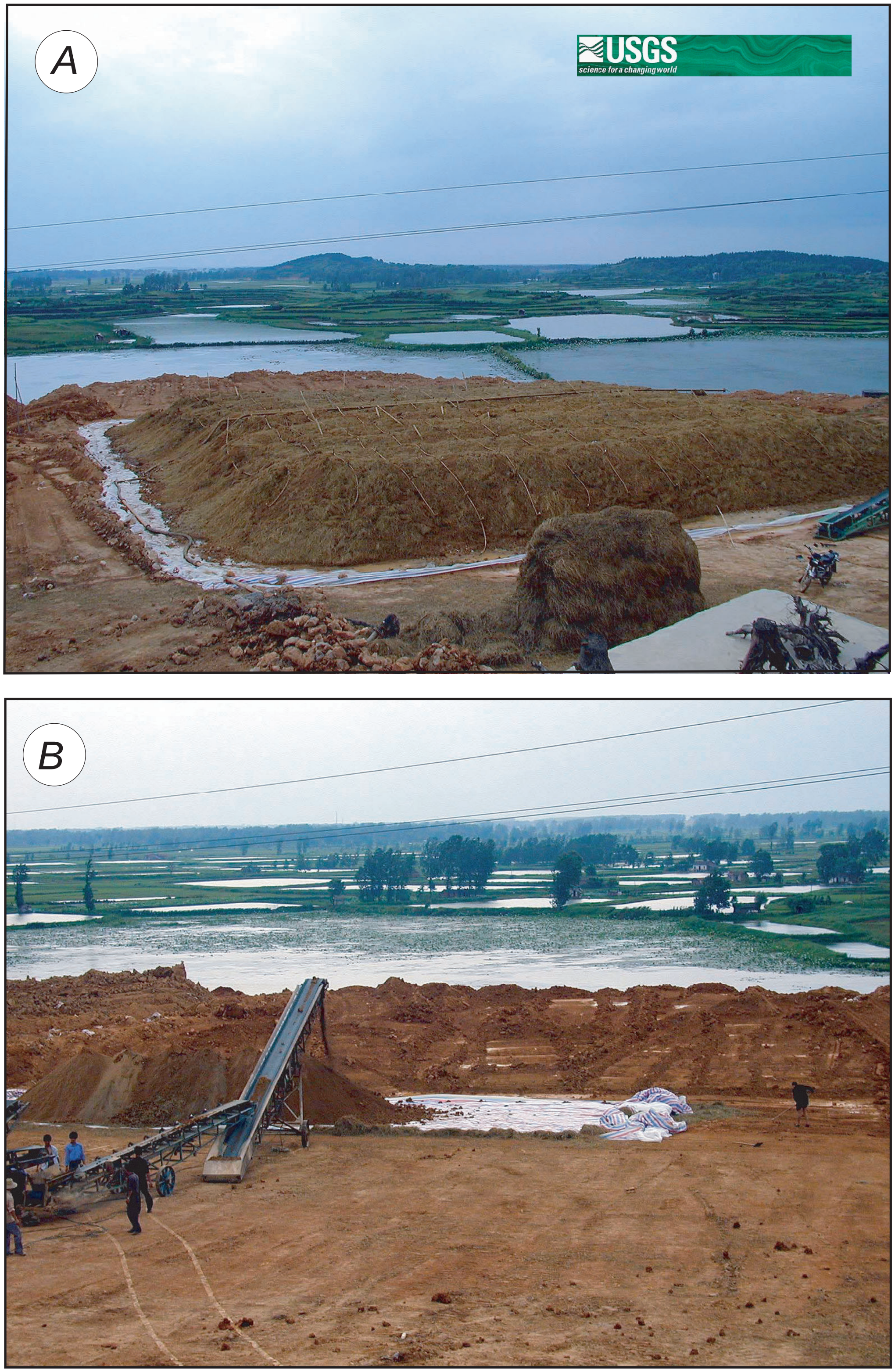


Figure 5-31. Photographs of heap-leaching operation at the Shewushan Au deposit, southeastern Hubei Province, Middle-Lower Yangtze River area. (*A*) Heap leach pad sitting on plastic sheeting and encased in straw to prevent evaporation. (*B*) Coveyor belt loading of new pad from crusher. Looking north towards Yangtze River plane. Mining area No. 2 on west end of Shewushan Mountain.

The regional tectonic setting of the Shewushan Au deposit involves the Puqi-Jiayu region in southern Hubei Province that is geotectonically situated along the northern limb of the Jiangnan anticline in the central part of the Yangtze fold-depression zone (not shown on figures). At the end of Paleozoic Era, the south China Proterozoic basement uplifted in the Fushan-Jiuling area in the south of the region and wide spread thrust and detachment faulting took place throughout in the anticlinal fold system. The Shewushan Au ore deposit is located at the front part of this system of compression, slip, and detachment (décollement).

Sedimentary rocks exposed in the mine area are provisionally assigned to the Silurian, Carboniferous, Permian, Jurassic, Cretaceous and Quaternary, although definitive identification of the highly lateritized rocks is in dispute. A 2,000–m-thick sequence of Silurian rocks is composed of shallow marine clastic rocks that are divided into the S_1g shale of the Gaojiabian Formation (Lower Series), in which graptolites are present, the S_2f siltstone of the Fentou Formation (Middle Series), and the S_3m sandstone of the Maoshan Formation (Upper Series). A 1,500–m-thick sequence of Carboniferous rocks in the Shewushan area are C_2h limestone of the Huanglong Formation (Middle Series) and C_3c limestone of the Chuanshan Formation (Upper Series).

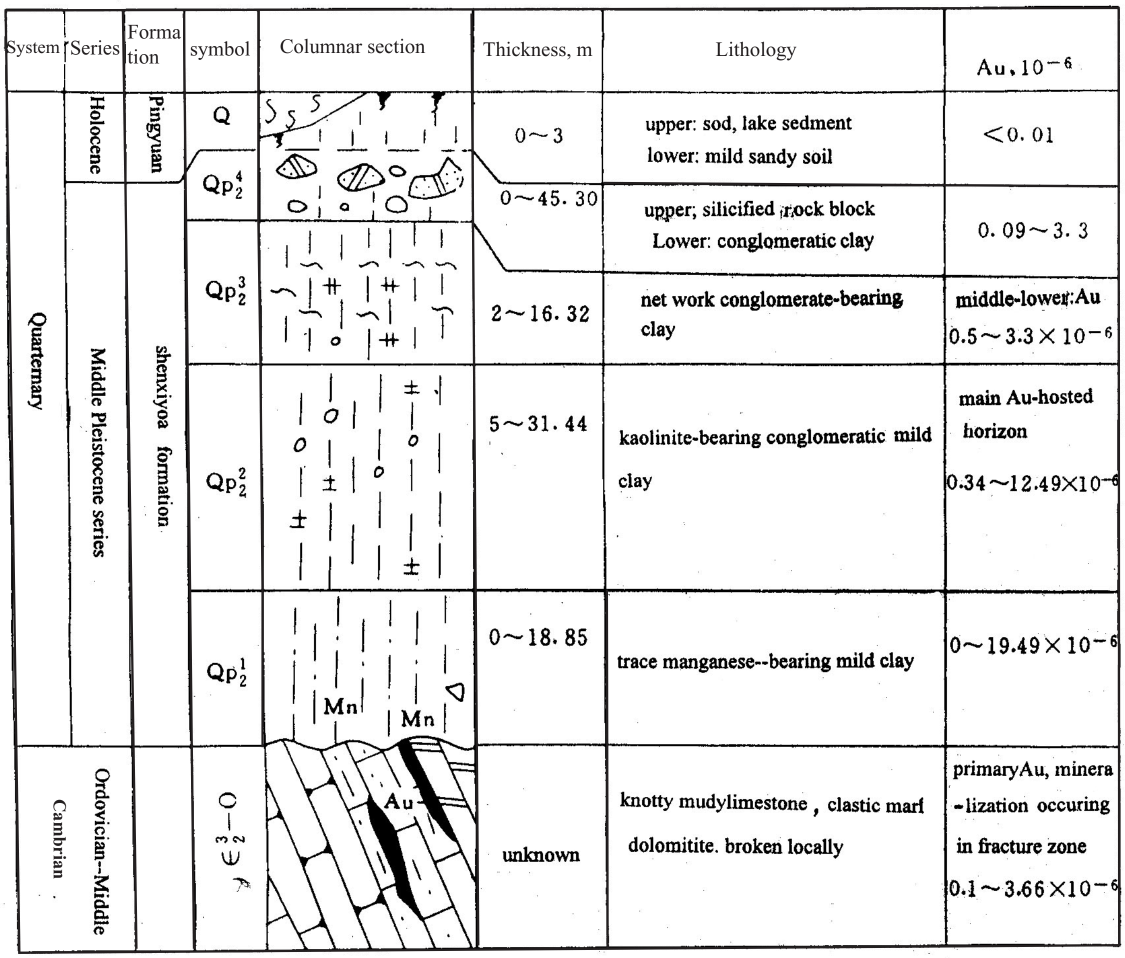
The 440–m-thick Permian sequence of sedimentary rocks is well exposed in the mining district and divided into P_1q limestone of the Qixia Formation, P_1m limestone of the Maokou Formation (Lower Series), and P_2w limestone of the Wujiaping Formation (Upper Series). The former is composed of limestone, chert band-bearing limestone and cherty limestone. The latter is composed of limestone and siliceous band-bearing limestone. Gold ores generally are hosted in P_1q and P_1m and Au grades generally are higher in P_1m than in P_1q.

The Jurassic stratigraphic sequence in the Shewushan area is represented by: (1) the 170–m-thick Wuchang Formation (J_1w), composed of conglomerate, sandstone, siltstone, silty mudstone, and quartz sandstone; and (2) the 220–m-thick Zidongjing Formation (J_2z), composed of sandy mudstone, quartz sandstone, and siltstone. Quaternary age rocks are widely exposed sedimentary red beds, and river and lake sedimentary rocks.

Complex folds and faults dominate the structural setting of the Shewushan area. The main structure is the northeast-trending overturned Shewushan anticlinal fold. The core of this anticline contains Silurian sedimentary rocks and the two limbs are composed of Carboniferous, Permian, and Jurassic rocks. The southern limb dips southeast at an angle of 45 to 80° and the northern limb to dips northwest at angle of 10° to 20°. The other main structure is a regional-scale, north-northeast-striking fracture zone. Subsidiary faults associated with this fracture zone are well developed and three groups strike east, northwest, and northeast. In addition, interformational thrust faults are present in the stratigraphic units and are important in the localization and control of Au in the Shewushan Au deposit.

The Shewushan Au deposit lies in a lateritic profile and is characterized by strong weathering superimposed over Au–mineralized cataclastic sedimentary rocks (figs. 5-32, 5-33, and 5-34). Tectonite, probably related to low-angle thrust faults on Shewushan Mountain (fig. 5-27), predates laterite and is composed of silicified cataclasite, crackle breccia, and argillized and carbonitized cataclasite. These rocks form a silica cap above most of the soft lateritic ore, and a local outcrop is in the form of a snake's head on the mountain (snake head mountain means *Shewushan*) (fig. 5-30). Beneath this silica cap is argillized cataclasite that is relatively rich in Au.

Ore is hosted in saprolitic rocks that some workers refer to in terms of sedimentary fabrics, as if they were Tertiary sedimentary rocks (muddy, silty and conglomeritic to muddy textured in an earthy, mottled network) as in figures 5-32, 5-33, and 5-34. Laterite nomenclature (saprolite, mottled zone, pisolites etc.) also is appropriate for the fabrics in these rocks (figs. 5-35. 5-36, 5-37, and 5-38). Gold grade is directly proportional to increments of relict micro-grained quartz in the rocks and Au mainly is present as adsorption Au in and on clay minerals. Gold also is present as inclusion Au in relict hypogene sulfide minerals and chalcedonic quartz. Ore is further divided into: (1) a silicified argillaceous breccia-type; (2) weakly silicified limestone breccia-type; (3) argillized cataclasite-type; (4) weakly silicified limestone breccia-type; and (5) silicified rock-type. The first three types are weathered lateritic ores and they dominate the deposit (figs. 5-35, 5-36, 5-37, and 5-38). The last two types comprise semi-weathered ore.



The Strata Columnar Section of Shewushan Au mine Distrit

Figure 5-32. Stratigraphic section of the Shewushan Au deposit, Middle-Lower Yangtze River area, Hubei Province. This section uses stratigraphic nomenclature as if the lateritic profile were Tertiary sediments (note particularly the lithology column). Lateritic nomenclature also is appropriate. Modified from No. 4 Geological Team of Hubei Province.

Oxide ore mineralogy is complex and includes more than 20 minerals, although kaolinite, hydromica, quartz, and chalcedony are the main minerals, and account for 99 percent of the ore, and include lesser amounts of limonite, goethite, and pyrolusite. Other hypogene or gangue minerals are barite, pyrite, realgar and orpiment, chlorite, scheelite, arsenopyrite, limonite, goethite, anatase, stibnite, galena, epidote, spinel, zircon, and corundum, as well as carbonate minerals, such as calcite, dolomite, and ankerite.

Metallogenesis of the Shewushan Au deposit is similar to many red earth lateritic Au deposits in southwest China (see Chapter 1) that are divided into primary and secondary stages: (1) A primary Au stage formed along an interformational thrust fault zone in units P_1q and P_1m, especially at the intersection of the thrust fault and northeast- and northwest-striking fractures where strong silicified cataclastic zones were over-printed by hydrothermal silicification, argillic alteration, and deposition of barite, pyrite, realgar, and orpiment. These processes are similar to those described by Webster and Mann (1984) and Butt (1989). Some workers suggest that dark bands in the lateritic profile are Silurian phyllite (fig. 5-36*B*), similar to the host rocks at Zhanghai Au deposit, but others interpret these zones as reduced bands in the lateritic profile (fig. 5-28*D*).

Silicification is widespread, on a mine scale, and silica intensity decreases downward along the two sides of ridge above the deposit and from the surface to the clay-rich lateritic horizons near the high Au grades. Silicification is dominated by planar replacement, then by filling of veinlets. A secondary Au stage involves actual formation of the lateritic, red earth Au deposit. During the Yanshanian period, block faulting resulted from north-northeast tectonic uplift and subsidence that was induced by detachment faulting of the folded Paleozoic and Mesozoic sedimentary rocks in the north, and brittle and ductile deformation along the regional-scale Jiangnan fault depression (not shown on figures).

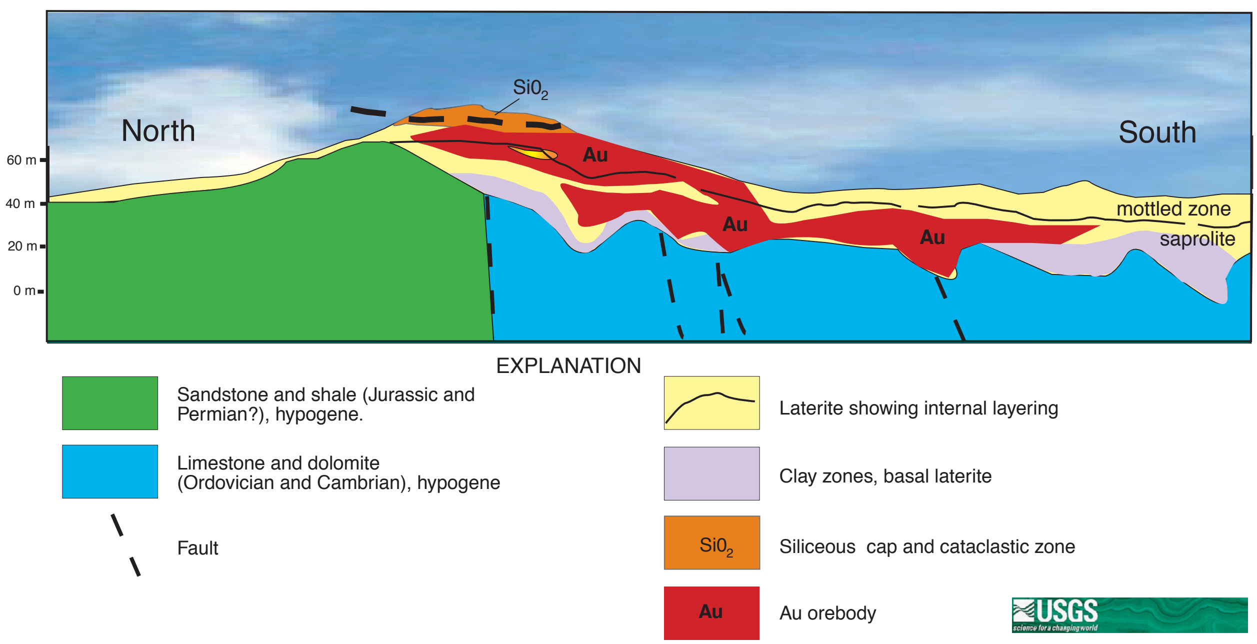
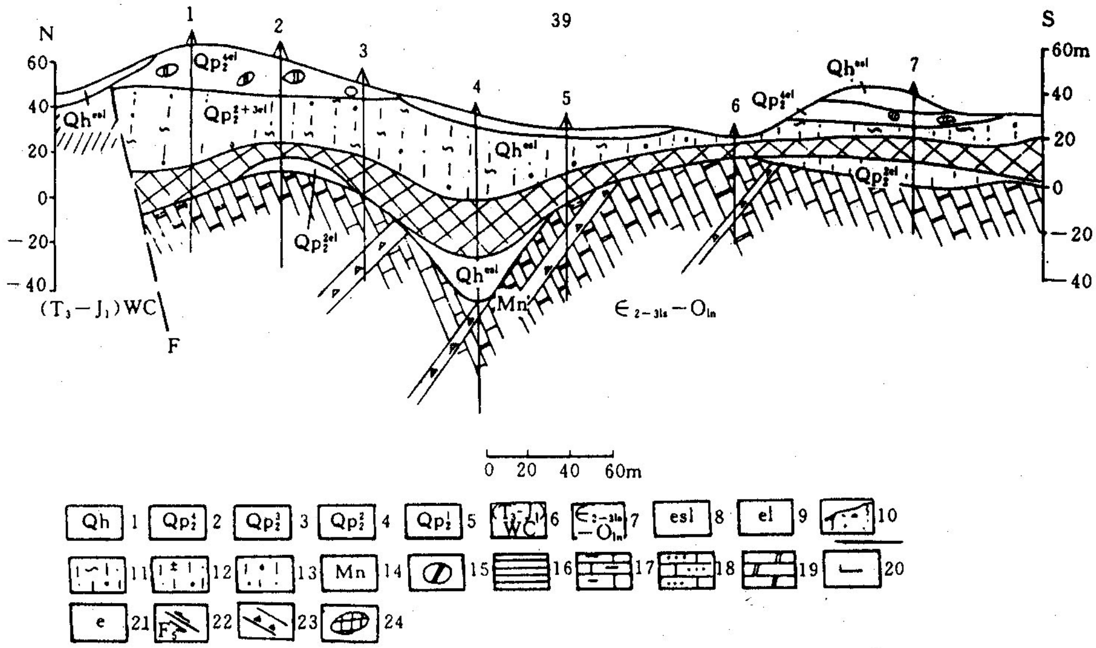


Figure 5-33. Geologic cross section through the Shewushan Au deposit, southern Hubei Province, Middle-Lower Yangtze River area showing lateritic profile and its relation to ore. The orebody is present over the faulted contact between two major lithotectonic units and contains a siliceous, cataclastic cap. Morphology of the orebody closely follows the layering in the lateritic profile, but also follows closely the near horizontal cataclastic zone.



The Profile of 39 Line of Shewushan Au Deposit

1.--Holocene Series:residual-slope wash, drifted materal 2. No. 4 member of Middle Pleistocene Series

3. No. 3 member of Middle Pleistocene Series: network conglomeyatic mild clay

4. No..2 member of Middle Pleistocene Series: kaolinite-bearing conglomeyatic mild clay

5. No..1 member of Middle Pleistocene Series: conglomeyatic mild clay

6.Upper Triassic Series-Lower Jurassic series (Wuchang Group)

7. Upper Cabrian-Lower Ordovician (Louguanshan Group--Nanjinguan formation)

8. residual-slop wash 9. residual materal 10. sod 11. net work conglomeratic mild clay

12. kaolinite-bearing conglomeratic mild clay 13. coglomeratic mild clay 14. manganomelane

15. silicified rock block 16. shale 17. knotty mudlimestone 18. clastic limestone 19. dolomitite

20. calcareous 21. bioclastics 22. thrust fault 23. fracture zone 24. Au ore body

Figure 5-34. Cross section through the No. 1 orebody, Shewushan Au deposit, Middle-Lower Yangtze River area, Hubei Province. Section shows interpreted infuence of Tertiary sedimentation on the lateritic profile. Modified after the No. 4 Geologic Team of Hubei Province.

Figure 5-35. Photograph of open cut, Shewushan No. 1 orebody, showing base of laterite zone, southeasternHubei Province, Middle-Lower Yangtze River area. Unlateritized mound (arrow) is dolomitic limestone at base of laterite.

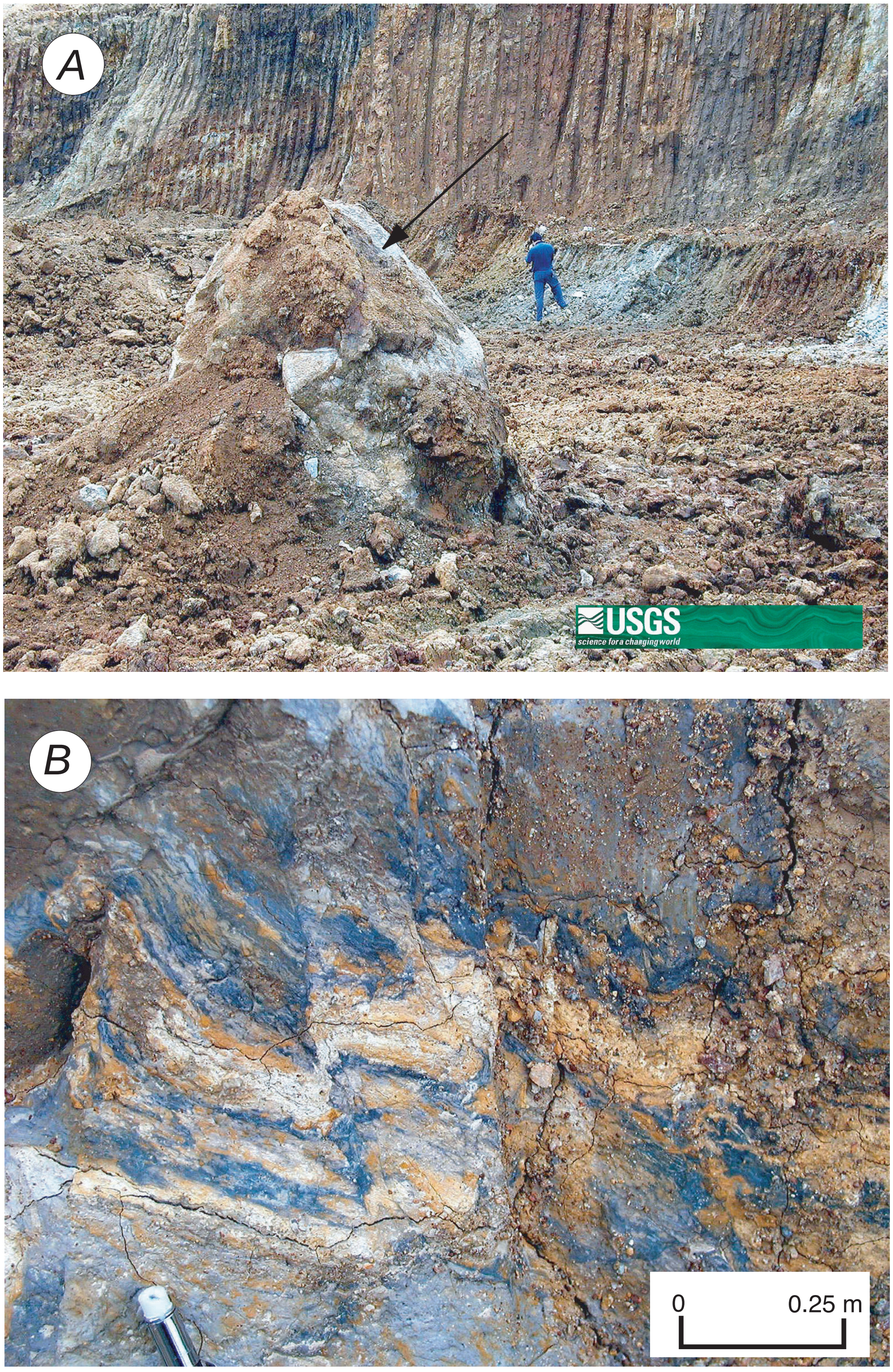


Figure 5-36. Photographs of textures and colors caused by laterite in the Shewushan Au deposit, southeastern Hubei Province, Lower Yangtze River area. (*A*) Hypogene, hard dolomite block at the base of the laterite profile at the bottom of the open pit mine (arrow). Note streaks on high-wall, caused by back-hoe digging in saprolite zone. (*B*) Partially lateritized black slate above saprolite. This color has been interpreted as Silurian age slate by some workers.

Since at least the Middle Tertiary, the Shewushan Mine area and hypogene Au ore has been exposed to sub-tropical climatic weathering. The yearly average temperature is 20 ºC with an average rainfall of 1,500 mm. Chemical weathering remains very strong. The Puqi-Jiayu region has hill and plain topography in the eroded Yangtze River valley dominated by alluvial geomorphology between a distance of 20 m above and below an elevation of 80.5 m above sea level. The geomorphology of the Puqi-Jiayu region is complex, because the river system and associated underground aquifers have interacted with the extensive Paleozoic and Mesozoic carbonate rocks, and these carbonate rocks developed a regional-scale micro- and macro-karst system. Karst caves and cracks were geometrically and hydrologically linked to tectonic cataclastic zones that were connected to surficial and underground water flow, which resulted in the development of a deep laterite profile. Gold-bearing silicified rocks are partial products of the residual redistribution of silica during weathering and also may have been a primary source of silica that weathered and dissolved to form the Shewushan lateritic (red earth) Au deposit.

Original spatial zonation of cataclasite and alteration has directly affected the redistribution of geochemical element anomalies in the vertical laterite section. The top parts of the deposit are dominated by the silicified cataclastic rock-type Au ores, the middle by kaolinized cataclastic rocks, and the bottom by hypogene pyrite, realgar, orpiment, and several carbonate alteration minerals.

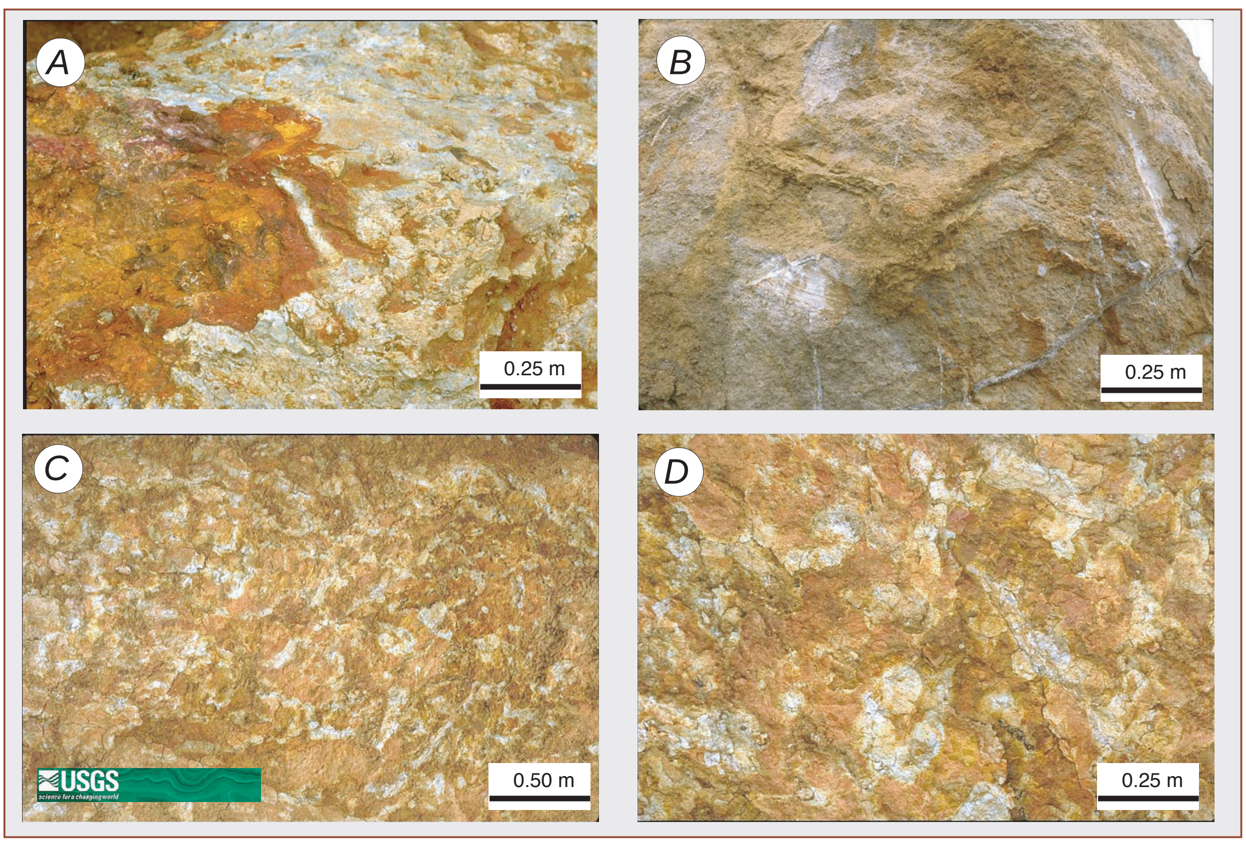


Figure. 5-37. Photographs of laterite textures, Shewushan Au deposit, southeastern Hubei Province, Lower Yangtze River area. (*A*) Duricrust of black sandstone and shale. (*B*) Unlateritized lower limestone at the bottom of open pit with cracks filled by oxide minerals. (*C*) Saprolite zone. (*D*) Close-up of mottled saprolite zone.

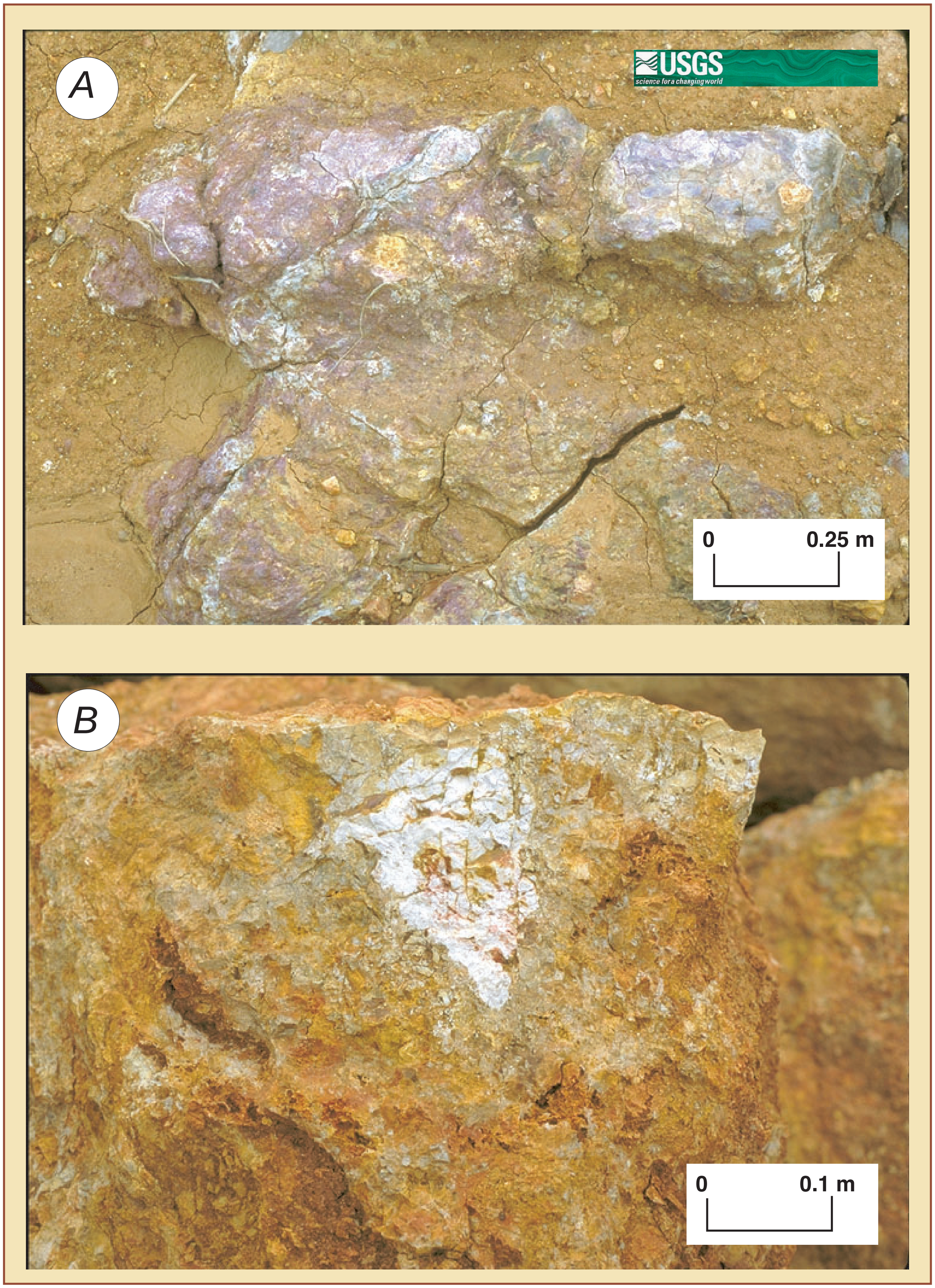


Figure 5-38. Hand-speciman scale photographs of ore textures and colors in the Shewushan Au deposit, southeastern Hubei Province, Lower Yangtze River area. (*A*) maroon mottled color and texture above saprolite zone. Note lack of primary texture. (*B*) Crackle breccia in silicified cap zone. Note boxworks in vugs formed by crackling.

Hypogene mineralogy reported from the Shewushan Au deposit, such as realgar, orpiment, and the disseminated nature of the sulfide minerals is similar to Carlin-type Au deposits. Much of the original geochemical profile has been removed or redistributed during lateritization. Anomalous concentrations of F and Hg are present (Appendix IV) and moderate amounts of Cu, Pb, and Zn remain in oxide ores. These characteristics are compatible with the lateritization of a Carlin-type deposit similar to the Zhanghai Au deposit.

Tongling area, Anhui Province

The Tongling area, Anhui Province contains numerous polymetallic skarn and replacement deposits that are associated with contact zones around Jurassic intermediate plutons and stocks, usually hosted in narrow carbonate-rich horizons of Carboniferous and Permian rocks (Kuo, T., 1957; Fan, P.F., 1984; Ge, C.H., and others, 1990; Zhao Y., 1991; Zhao Y., and others, 1990; Xu and others, 1992,). The area contains 300,000 tonnes Cu in reserve, much from Cu–Fe skarns like the Tongguanshan, Fenghuangshan, and Shizishan deposits. Gold is mined from sulfide ores, but mainly is extracted from the gossanous upper parts of these deposits. The Xinqiao, Mashan, and Huangshiloashan Au deposits were visited in 2000. In addition to these deposits, small Carlin-type Au deposits are present in some Silurian sandstone, and the newly discovered disseminated Jiaochong Au deposit, 2.5 km south of the Huangshiloashan deposit, contains high concentrations of Zn, Pb, As and S, and it is hosted in Permian limestone (fig. 5-1). Stratigraphy exposed in the Tongling Mining District consists of northeast-striking Devonian, Carboniferous, Permian, and Triassic Series rocks (fig. 5-39). The four host stratigraphic horizons for orebodies in the Tongling area are: (1) middle Carboniferous Huanglong Formation

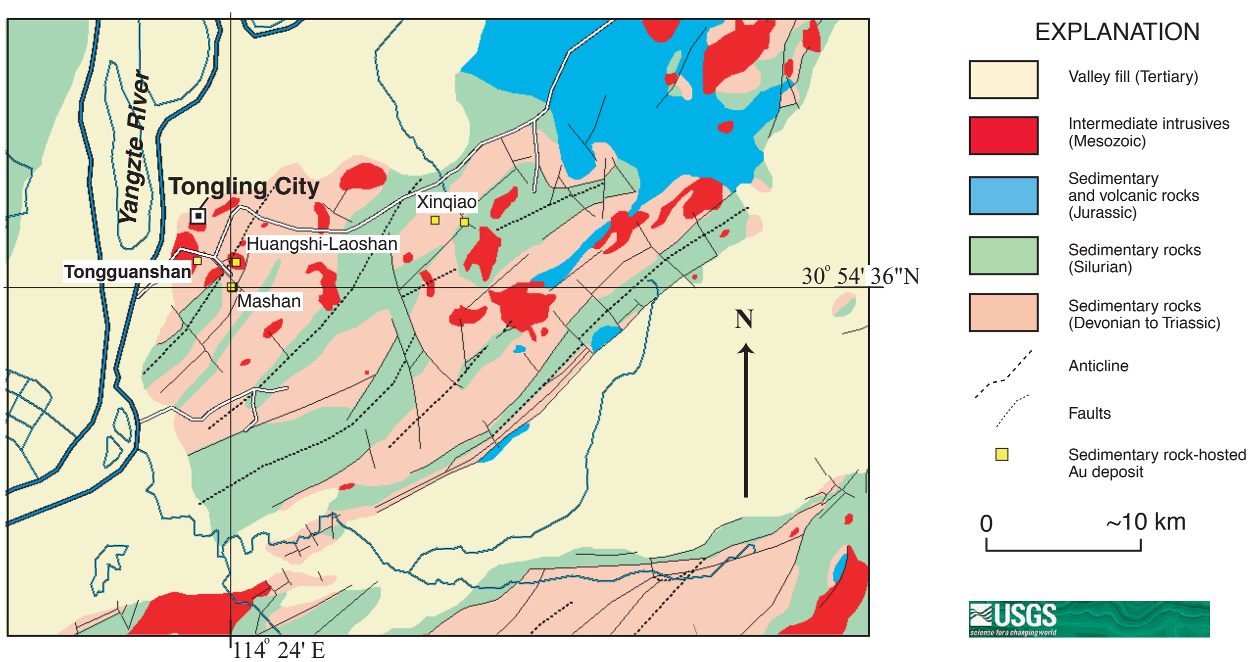


Figure 5-39. Geologic map of the Tongling area, Anhui Province, Middle-Lower Yangtze River area showing location of deposits discussed in text. For location, see Fig. 5-1. Latitude and longitude are approximate.

(C_2h), a 30–m-thick unit consisting of bedded limestone, dolomitic limestone, and dolomite; (2) the overlying late Carboniferous Chuanshan Formation (C_3c), a 60–m-thick, bedded limestone and bioclastic limestone, which is strongly marbleized; (3) early Carboniferous Gaolishan Formation (C_1g), a 30–m-thick arenaceous shale interlayered with thin-bedded argillaceous shale, medium- to thick-bedded quartz sandstone, and quartzite; and (4) the Lower Permian Qixia Formation (P_1q), a 200–m-thick bituminous limestone with chert bands and concretions.

The Tongling Mining District is located at the intersection of the Shujiadian and Dachengshan anticlines, and Shengchong syncline. There are two groups of fractures in the district. The main group is northeast-striking and present in the shale between the P_1q and C_3c units and also in arenaceous shale between units C_2h and C_1g, roughly parallel to the strata. Fractures in these shale units form large cataclastic zones and host Au orebodies, particularly between units P_1q and C_3c. Fractures in arenaceous shale are slip and detachment faults, which were conduits for magma and ore fluids and also host Au orebodies. The second fracture group is a set of northwest- and north-striking fractures roughly perpendicular to the axes of the district-scale anticlines.

Hydrothermal alteration in the intrusive rocks and the wall rocks is dominated by the development of skarn, which consists of silica, marble, epidote, dolomite, and wollastonite. Ore-stage minerals mainly are pyrite, then chalcopyrite, pyrrhotite, arsenopyrite, magnetite, and siderite, as well as sphalerite, galena, tetrahedrite-tennantite, hematite, and Au and Ag minerals. Ore mainly is present as mantos with massive, disseminated, and breccia textures along the host stratigraphic horizons. Gold mainly is present as inclusions in sulfide minerals, but also is present along fractures. Weathering of the deposits has produced stratabound gossanous zones with massive goethite, hematite, pyrolusite, and psilomelane, as well as minor pyrite and native microscopic Au.

Good examples of sedimentary rock-hosted ores in the Tongling area are present at the Tongguanshan Cu–Fe–(Au) skarn and the gossanous Au deposits of Xinqiao, Mashan, and Huangshiloashan.

Tongguanshan Cu–Fe skarn

The Tongguanshan Cu–Fe–(Au) skarn deposit is the best known and one of the largest skarn deposits in the Tongling area (Fan, P.F., 1984; Ge, C.H., and others, 1990). The deposit lies along the southeast contact of an elliptical 136 to 158 Ma pluton intruded into northeast-striking anticlines and synclines in the Guichi-Fanchang fold and fault belt (fig. 5-39). Ore is present as stratabound bodies, pipes, veins and locally as stockworks and disseminations. The main commodities recovered are Cu, Fe, Mo, S and Au. Primary ore-stage minerals are pyrrhotite, pyrite, magnetite, and chalcopyrite, as well as lesser amounts of marcasite, molybdenite, chalcosite, galena, arsenopyrite, bismuth minerals, stibnite, and local scheelite. Gangue and skarn-related minerals include andradite and grossular garnet, diopside, wollastonite, serpentine, scapolite, vesuvianite, epidote, magnetite, actinolite, tremolite, biotite, sericite, quartz, chlorite, muscovite, and talc. Zoning and complex paragenetic sequences are described by Ge, C.H. and others (1990). These minerals are characteristic of pluton-related skarn deposits and are common in other deposits in the Tongling Mining District.

Xinqiao Au deposit

The Xinqiao Au deposit is located at E 117°58 36''and N 30°55'06''in Xinqiao township, Tongling County, Anhui Province, Middle-Lower Yangtze River area approximately 20 km east from Tongling City (fig. 5-39). The Xinqiao Au deposit consists of 23 high-grade polymetallic orebodies and a total of 40 orebodies in the surrounding district. The deposits are referred to as pyritic Cu deposits (Ge, C.H. and others, 1990) and as residual (gossan) Au deposits (Xu, E.S. and others, 1992). The Xinqiao Au deposit is a large-size Au deposit with 170 million tonnes of ore in reserve. Gold reserve is 22.89 tonne Au, (average grade 5.5 g/t Au); Cu ore reserve 557,640 tonne, (ore grade 0.887 weight percent); Ag reserve 20.08 tonne, (ore grade 197.78 g/t Ag); pyrite ore reserve is 136,020,000 tonne, (S grade 31.32 percent). The main orebody is stratabound along a narrow stratigraphic interval of Carboniferous limestone and shale, striking northeast 57°, and dipping northwest 327°at an angle of 16°, extending horizontally for 500 m and vertically for 50 to 155 m (average 87 m); the average thickness is 7.5 m. Information about the Xinqiao Au deposit is from Team 812 of the East China Geological Exploration Bureau of MMI, Tongling and from Ge, C.H. and others (1990) and Zhao Y. and others (1993).

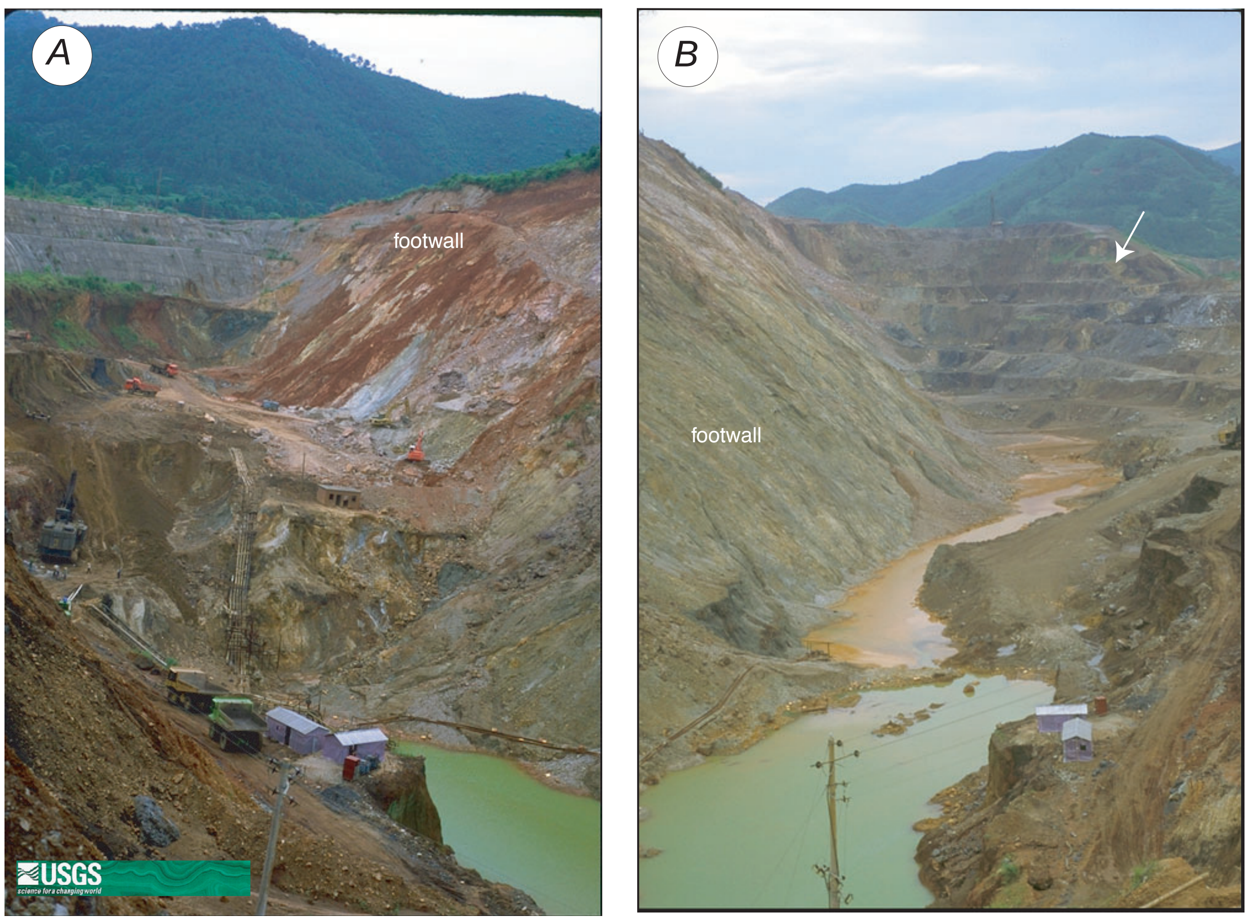


Figure 5-40. Photographs of the main open pit, Xinqiao Au deposit, Anhui Province, Middle-Lower Yangtze River area. (*A*) West endof pit witha concrete ground stabilization structure and intense Fe-oxide staining in oxide zone. (*B*) Looking east down the strike of the orebody with Permian footwall rocks on the left and light-colored dikes and sills (at head of arrow) along mineralized structure and bedding.

The Xinqiao Au deposit was discovered in 1958 by tracing gossan down dip. The mine is operated by the Chemical Industrial System, and geology and exploration assistance are provided by the East China Geological and Exploration Bureau of the Ministry of Metallurgical Industry. The deposit produces about 1.5 million tonnes of ore per year by mechanized open-pit methods (0.9 million tonnes per year) and by underground methods from circular shafts (0.6 million tonnes per year) (fig. 5-40). Hypogene ore and most oxide ores are processed through a flotation mill, where recent efforts have been placed to improve recovery of Au (fig. 5-41).

The Xinqiao Au deposit is located at the intersection of the southwest-plunging Shujiadan anticline and the northeast-plunging Dachengshan anticline on the northwest side of a domal structure (figs. 5-42 and 5-43). Ore is stratabound along several west-dipping, sheared horizons in the Upper Carboniferous limestone between the Chuanshan and Gaolisha Formations, particularly in the Lolingshan Formation at the Permian-Carboniferous boundary (figs. 5-44, 5-45).

The Jitou stock corps out in the Tongling Mining District in an area of 0.3 km^2. It is a Yanshanian Intrusion aged at 168 Ma and divided into three facies: a central quartz diorite, a transitional diorite, and a marginal diorite porphyry. Contact zones of the intrusion acted as conduits for ore fluid and provided the sites for ore precipitation. Apophyses of the stock were intruded along the ore host stratigraphic horizons as well as along selected horizons in the hanging wall Permian rocks (fig. 5-44 and 5-4).

Alteration in the intrusive rocks and the wall rocks is dominated by the development of skarn, which consists of silica, marble, epidote, dolomite, and wollastonite. Pyrite and chlorite may be related to retrograde stages of skarn, but also may have been added by a later hydrothermal event accompanied by kaolin and sericite. Pyrite, endoskarn, chlorite, kaolin, and sericite are most common in the intrusive rocks, whereas quartz, marble, pyrite, dolomite, epidote, and wollastonite are more common in the wall rocks. Chlorite is the most common in the hanging wall rocks and pyrite is more common in the foot wall rocks and is closely related to Au mineralization. Overprinting of alteration types is favorable for Au; for example, chlorite-pyrrhotite and dolomite and chalcopyrite are the main alteration assemblages associated with mineralized rock.

Figure 5-41. Photograph of flotation mill at the Xinqiao Au deposit, Anhui Province, Middle-Lower Yangtze River area for processing of pyrite-chalcopyrite ores.

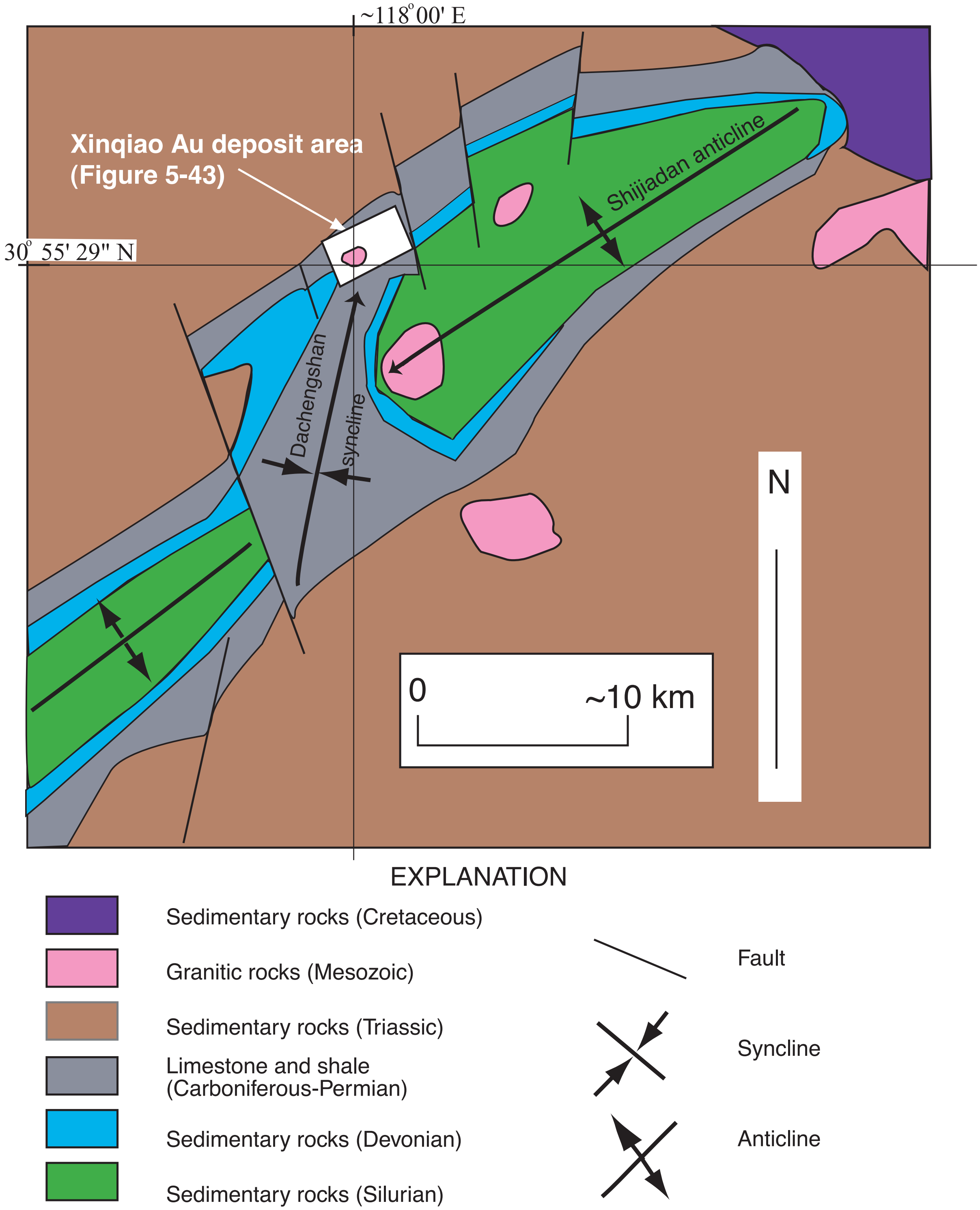


Figure 5-42. District geologic sketch map of the Xinqiao Au deposit area, Anhui Province, Middle-Lower Yangtze River area. The deposit is located along an anticlinorium in Carboniferous limestones. Scale and latitude and longitude are approximate. Modified from Team 812 of the East China Geological Exploration Bureau of MMI, Tongling and from Ge, C.H. and others (1990) and Zhao Y. and others (1993).

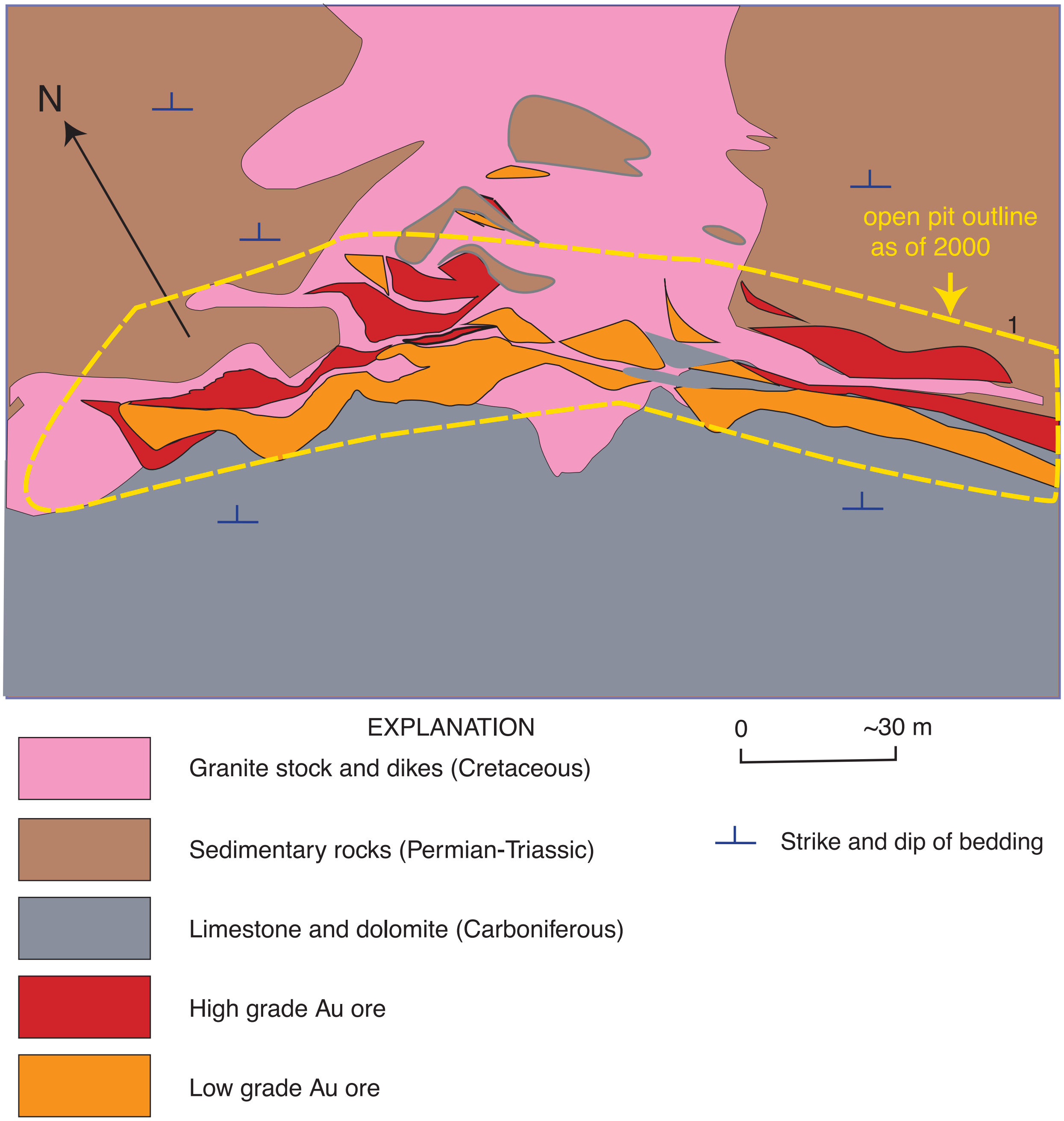


Figure 5-43. Geologic map of the Xinqiao Au deposit, Anhui Province, Middle-Lower Yangtze River area, showing approximate outline of open pit. For approximate location and longitude and latitude, see figure 5-42. Modified from Team 812 of the East China Geological Exploration Bureau of MMI, Tongling and from Ge, C.H. and others (1990) and Zhao Y. and others (1993).

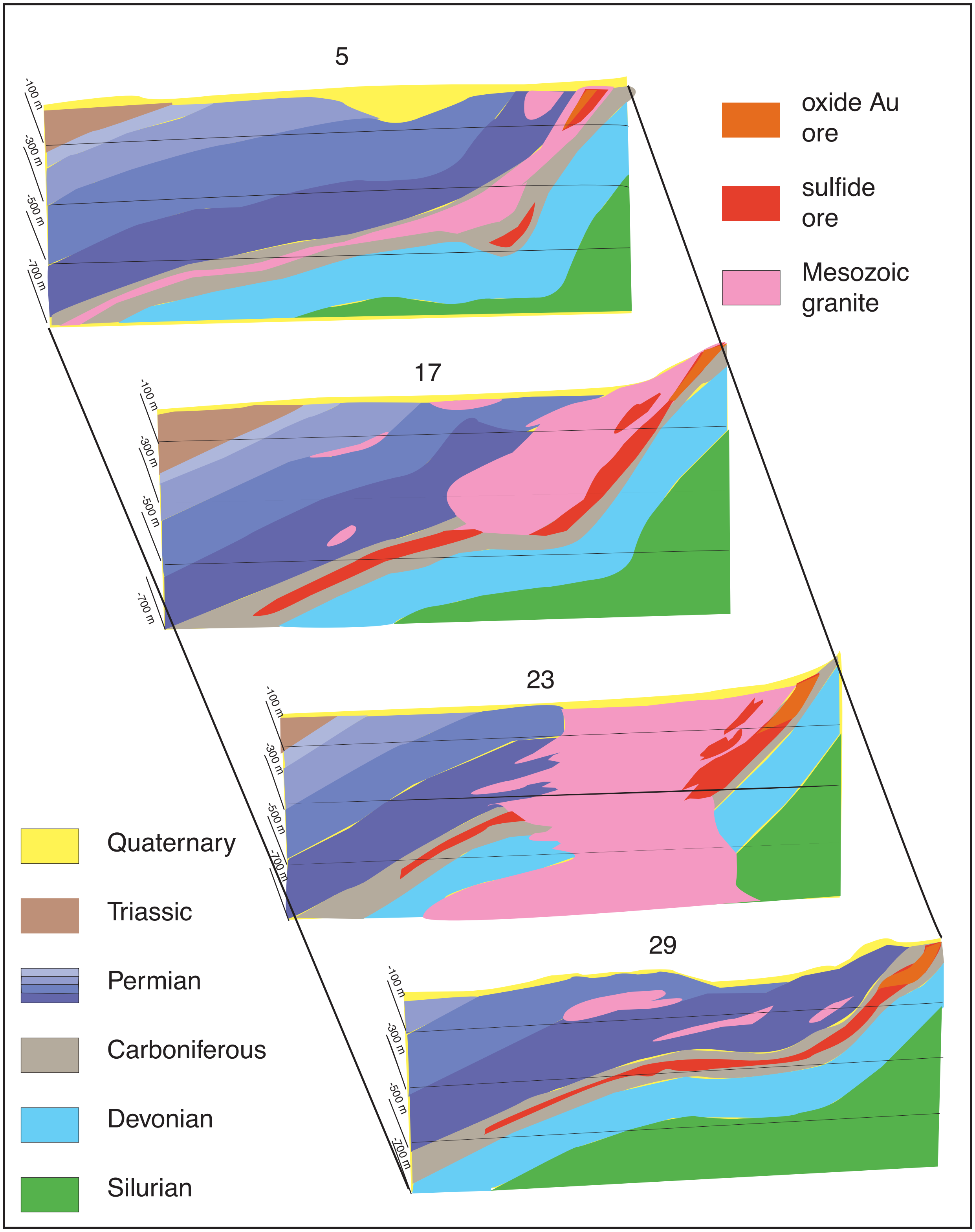


Figure 5-44. Geologic cross sections through the Xinqiao Au deposit, Anhui Province, Middle-Lower Yangtze River area. Numbers refer to section number. Looking southerly. Main ore horizon is the Carboniferous limestone and shale. Adapted from Team 812 of the East China Geological Exploration Bureau of MMI, Tongling and from Ge, C.H. and others (1990) and Zhao Y. and others (1993).

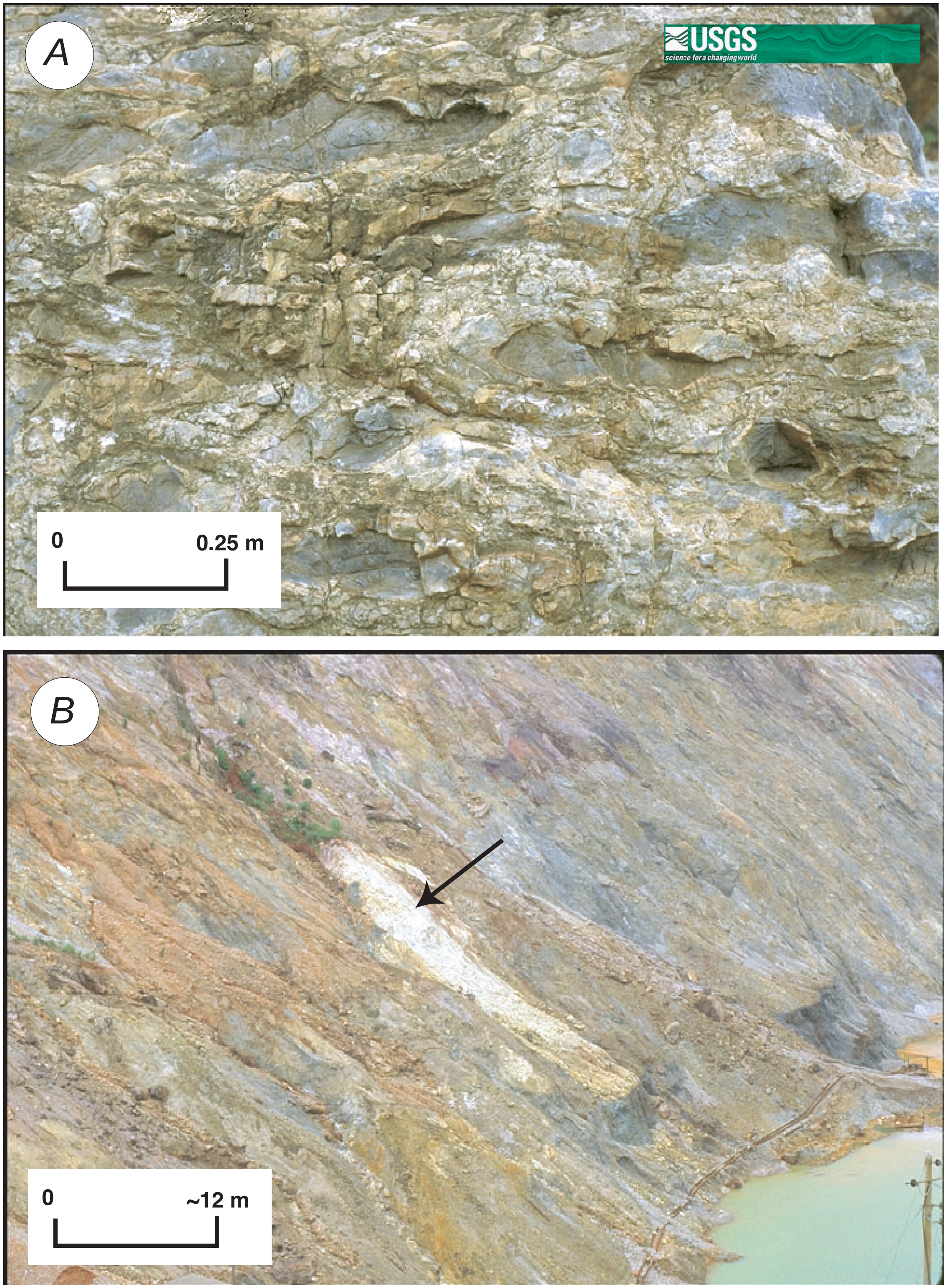


Figure 5-45. Photographs of rocks in the Xinqiao Au deposit mine, Anhui Province, Middle-Lower Yangtze River area. (*A*) Cherty Permian dolomite in hangingwall of deposit. (*B*) Mine face showing dip of foot wall strata and granitic intrusive invading the footwall rocks (white rock marked by head of arrow).

Hypogene ore minerals mainly are pyrite, then chalcopyrite, pyrrhotite, magnetite, siderite, as well as minor sphalerite, galena, arsenopyrite, tetrahedrite-tennantite, hematite, and Au–Ag minerals (figs. 5-46, 5-47, and 5-48). Main gangue minerals are calcite, dolomite, chlorite, and quartz, with lesser kaolinite, feldspar, calc-silicate minerals, minor sericite, and talc. The ore mainly is present as granular, replacement, inclusion textures and as massive, disseminated, and breccia textures, and in veins and veinlets. Gold mainly is present as inclusions in sulfide minerals, but it also is present along fractures. Chalcopyrite and pyrite as well as dolomite, chalcocite and minor pyrrhotite, sphalerite, magnetite and quartz all contain various amounts of Au in inclusions. Gold in fractures is intergrown with chalcopyrite, horsfordite, sphalerite, and pyrite. Oxide and gossanous Au ores are similar to those described below in the Mashan and Huangshiloashan deposits.

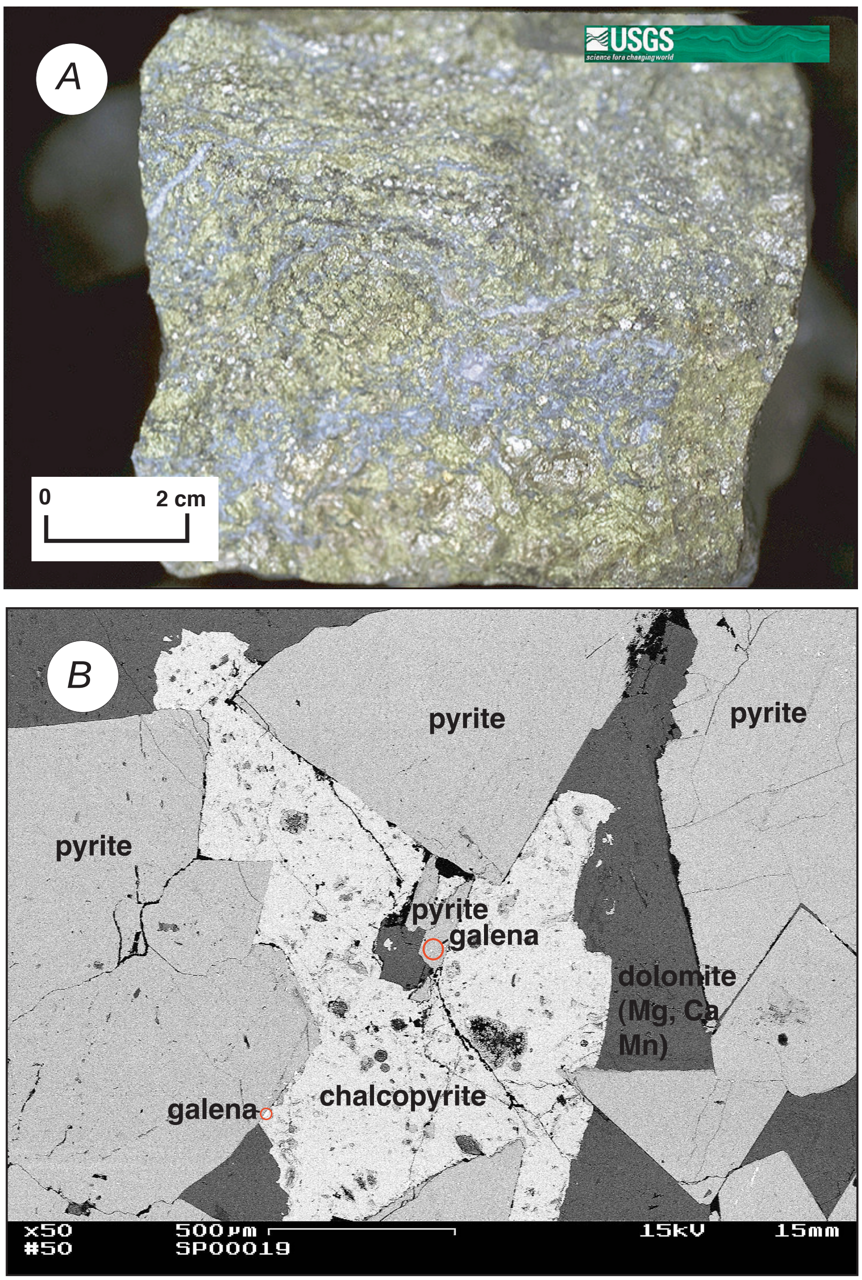


Figure 5-46. Photographs of sulfide-rich ore from the Xinqiao Au deposit, Anhui Province, Middle-Lower Yangtze River area. (*A*) Hand specimen of pyrite, chalcopyrite, and dolomite. (*B*) Scanning electron microscope back scatter image of polymetallic sulfide ore showing small inclusions of galena in chalcopyrite.

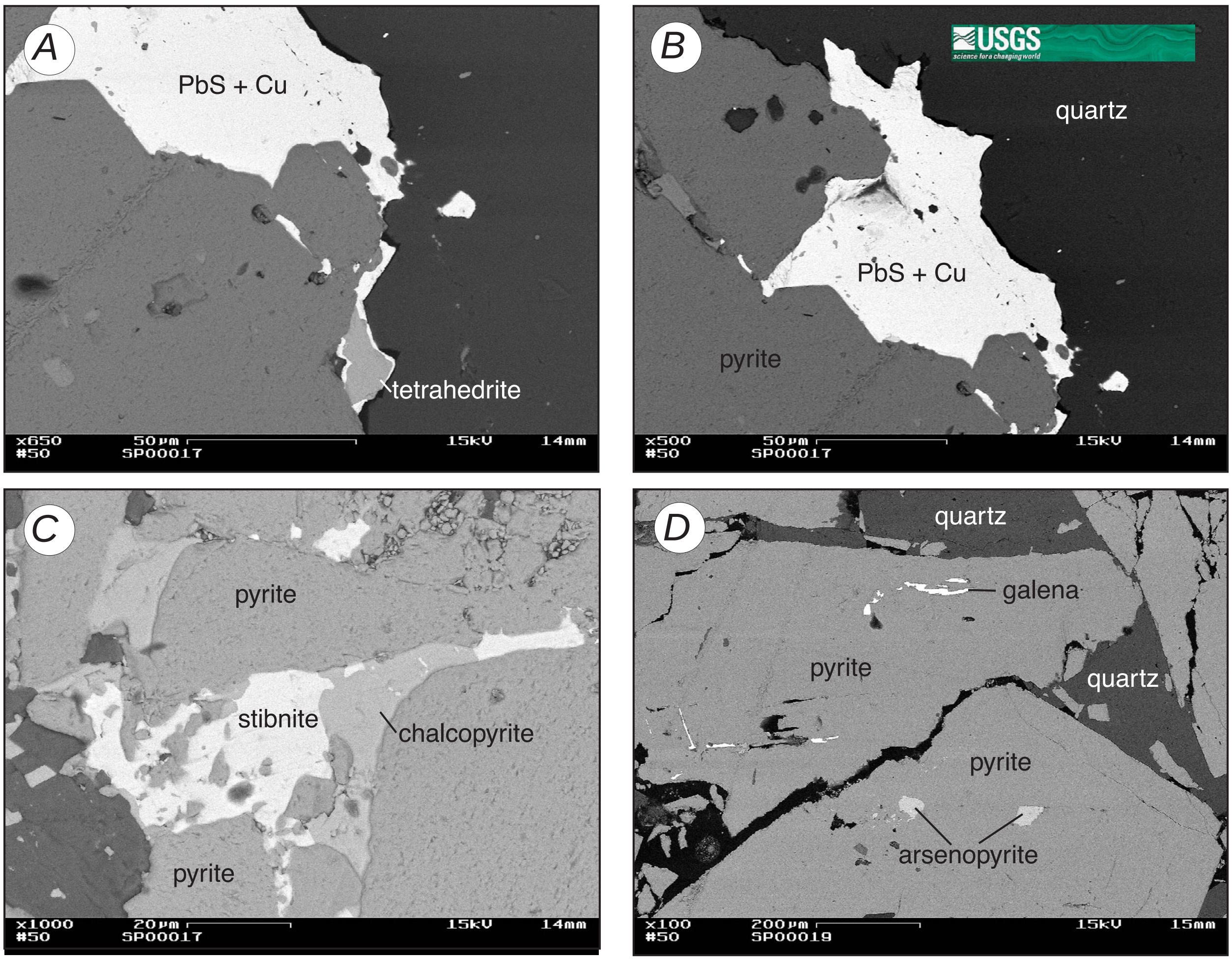
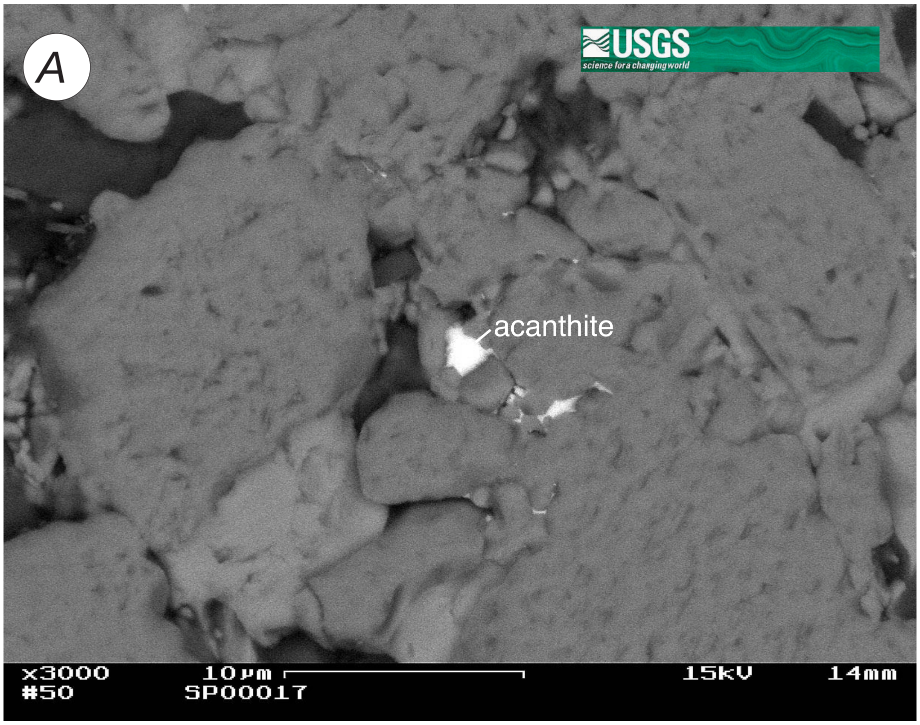


Figure 5-47. Scanning electron microscope back scatter images of polymetallic ores in the Xinqiao Au deposit, Anhui Province. (*A*) Tetradhedrite, pyrite, and Cu-rich galena. (*B*) Cu-rich galena, pyrite with quartz. (*C*) Pyrite, stibnite, and chalcopyrite. (*D*) Pyrite, galena, and arsenopyrite.



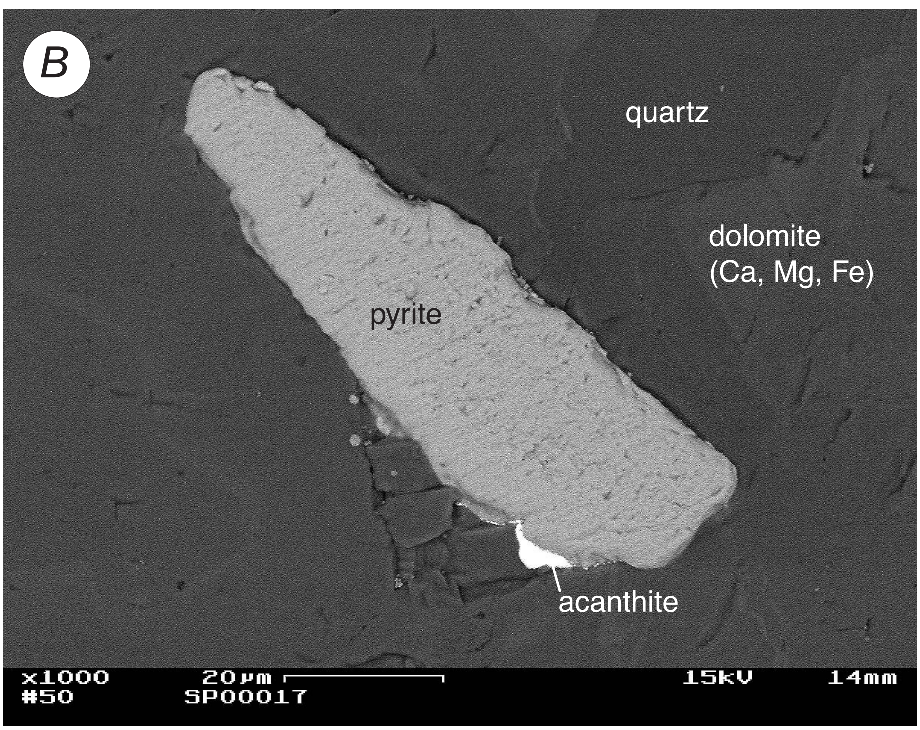


Figure 5-48. Scanning electron microscope backscatter images of acanthite habits in sulfide ores from Xinqiao Au deposit, Anhui Province,Middle- Lower Yangtze River area. (*A*) Silver mineral, acanthite, in pyritic ore. (*B*) Acanthite as growth-rim on pyrite grain.

Geochemically, the Xinqiao Au deposit hypogene ores have elevated concentrations of Ag and contain highly elevated contents of Cu, Pb, and Zn with moderate concentrations of As, Bi, Hg, and Sb (table 5-1). These elemental concentrations are not uncommon geochemical signatures of pluton-related or distal-disseminated sedimentary rock-hosted Au deposits. Values of $\delta^{34}S$ for chalcopyrite and pyrite from the Xinqiao Au deposit generally are +4.0 to 4.4 ‰, although one chalcopyrite sample had a value of –1.6 % (table 5-1).

Mashan Au deposits

The Mashan Au deposits are located at E. 117° 50' 00'' and N. 30º 55'10'' 2 km from Tongling City and about 6 km from the Yangtze River, Anhui Province (fig. 5-39). The elevation is 90.58 m above sea level. The Mashan Au deposits consist of about 44 orebodies surrounding the Mashan 137 Ma diorite (fig. 5-49). The main 2,000–m-long, north-striking, east-dipping, layered, stratabound orebody contains 475– to 120–m-long, 107– to 396–m-wide, and 4.35– to 64.9–m-thick Au–rich lenses (figs. 5-50,and 5-51). The deposit is a large Au deposit with Au reserve of 20.875 tonnes Au (average grade 6.3 g/t Au); pyrite ore reserve is 16,830,000 tonnes (ore grade of S = 30.95 weight percent); Cu ore reserve is 1,764 tonnes (average grade 0.47 weight percent Cu); Pb ore reserve is 7,703 tonnes (average grade 2.08 weight percent Pb); and Zn ore reserve is 28,925 tonnes (average grade 5.11 weight percent Zn). Information for the Mashan Au deposits is from the Non Ferrous Industrial Bureau and Team 812 of the East China Geological Exploration Bureau, Tongling (see also, Wang, B.H., 1996).

Ore pods are present as 100– to 300–m-long lenses along a 500 m dip length (figs. 5-50 and 5-51) with near-horizontal plunges that are elongate perpendicular to Au cross sections. Distribution of Cu and Au concentration is spatially separate and Cu contents of the Au ores generally are low, unlike the ores at Xinqiao Au deposit. Silver grades are about 15 g/t Ag. Mining is conducted by the Non Ferrous Industrial Bureau and consists of underground mining by shafts and adits into gossanous horizons. Ore is hauled to a mill complex (fig. 5-52*A*). About 33 weight percent of the ore taken to the mill is Au ore and the main commodities recovered are Au and S. Arsenic content of the ores is 1.7 to 1.8 weight percent. Lead and Zn are not common, although locally are as high as 20 to 30 weight percent combined.

Gossanous zones resulted from intense weathering of massive sulfide lenses. Outcrops of gossan are maroon to orange to earthy brown with 2– to 3–m-thick remnant-bedding layers. These gossanous zone locally are siliceous and contain local remnants of marble and wall rock (fig. 5-53).

Geotectonically, the deposit lies in the Guichi-Fanchang fold belt that contains the Middle-Lower Yangtze syncline, the Yangtze craton (not labeled on figures 5-1 or 5-39), and the regional-scale northeast-trending overturned southeastern limb of the Tongguanshan anticline, which is part of Tongling fold complex (fig. 5-39). The Mashan Au deposit lies on the east overturned limb of the northeast-striking Tongguanshan anticline. This anticline contains the Tongguanshan 152 Ma diorite to the southwest that hosts the Tongguanshan Fe–Cu skarn deposit. To the northwest, the west limb of the anticline hosts the Huangshiloashan Au deposit in the same stratigraphic horizons of Carboniferous calcareous sedimentary rocks. Therefore, the Mashan and Huangshiloashan Au deposits are equivalent deposits present on opposite limbs of the breached Tongguanshan anticline. The anticline contains the 137 Ma Mashan diorite in its central parts along the hinge line.

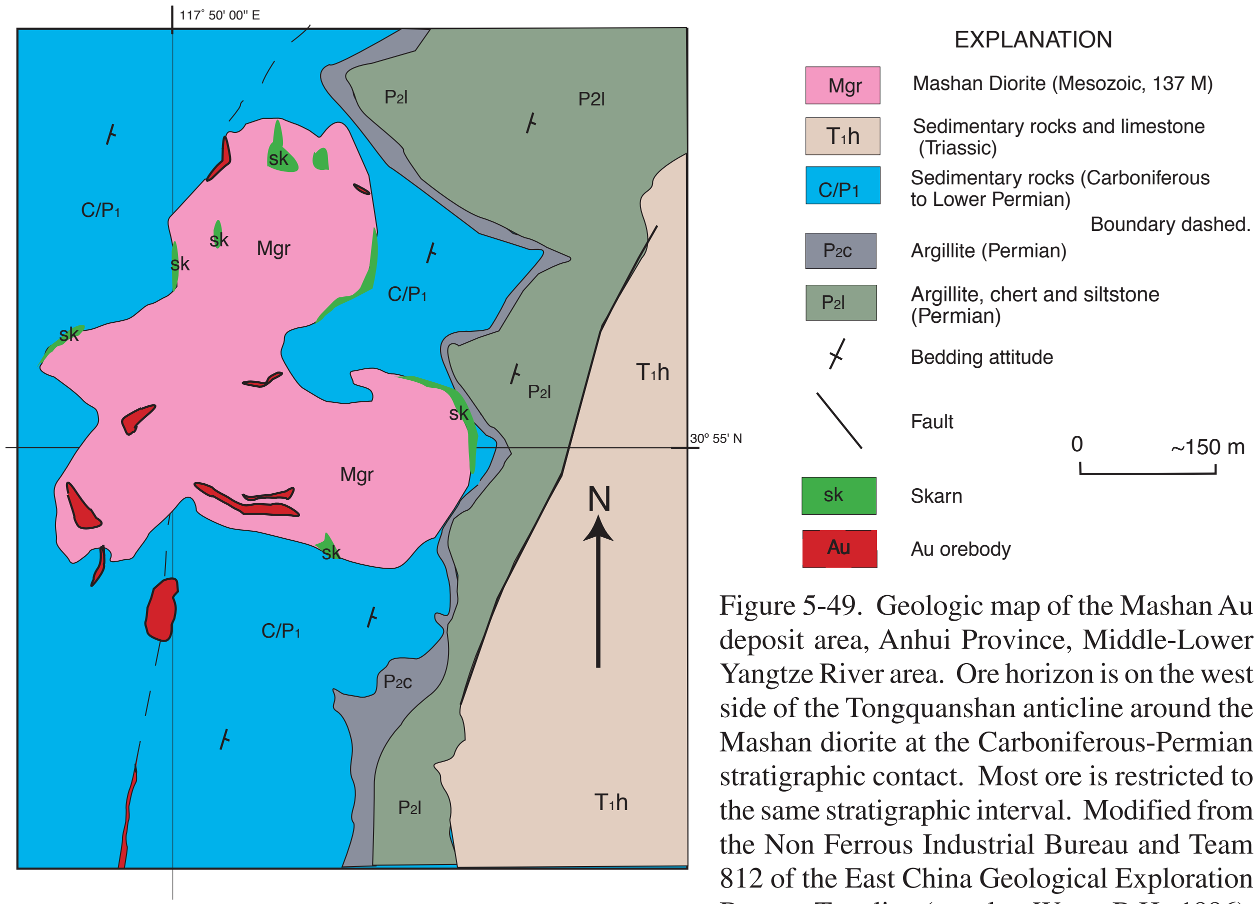


Figure 5-49. Geologic map of the Mashan Au deposit area, Anhui Province, Middle-Lower Yangtze River area. Ore horizon is on the west side of the Tongquanshan anticline around the Mashan diorite at the Carboniferous-Permian stratigraphic contact. Most ore is restricted to the same stratigraphic interval. Modified from the Non Ferrous Industrial Bureau and Team 812 of the East China Geological Exploration Bureau, Tongling (see also, Wang, B.H., 1996).

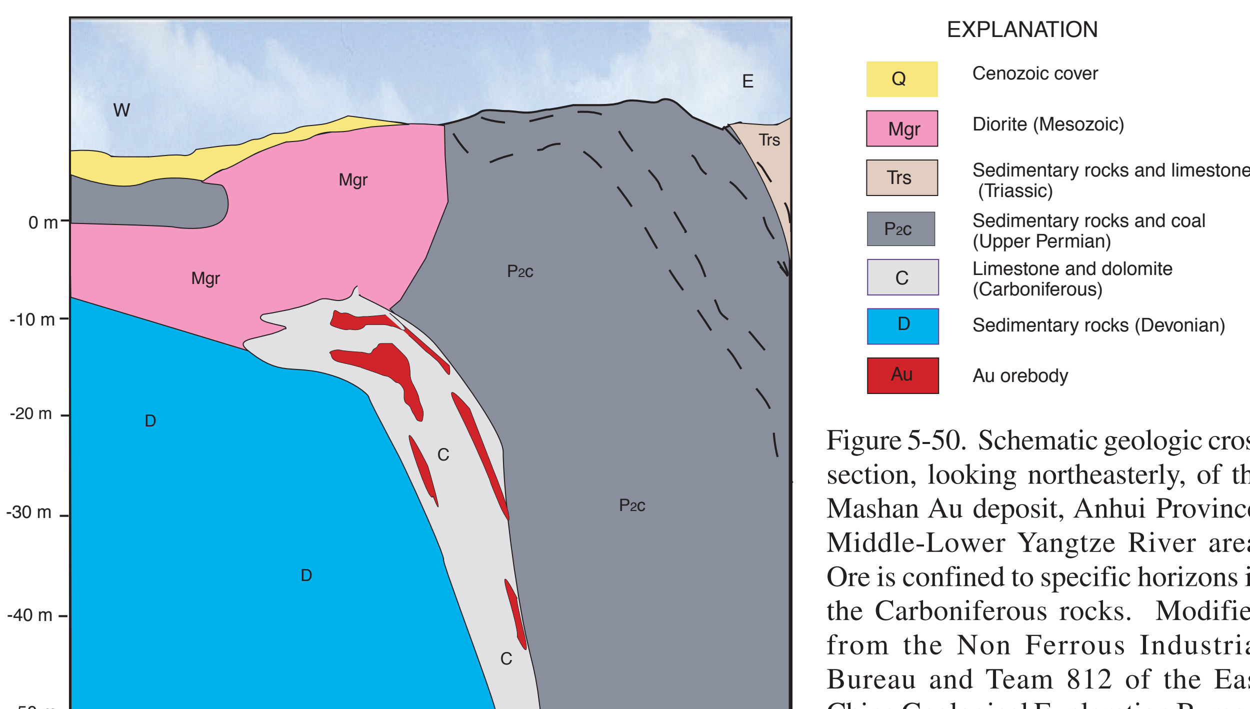
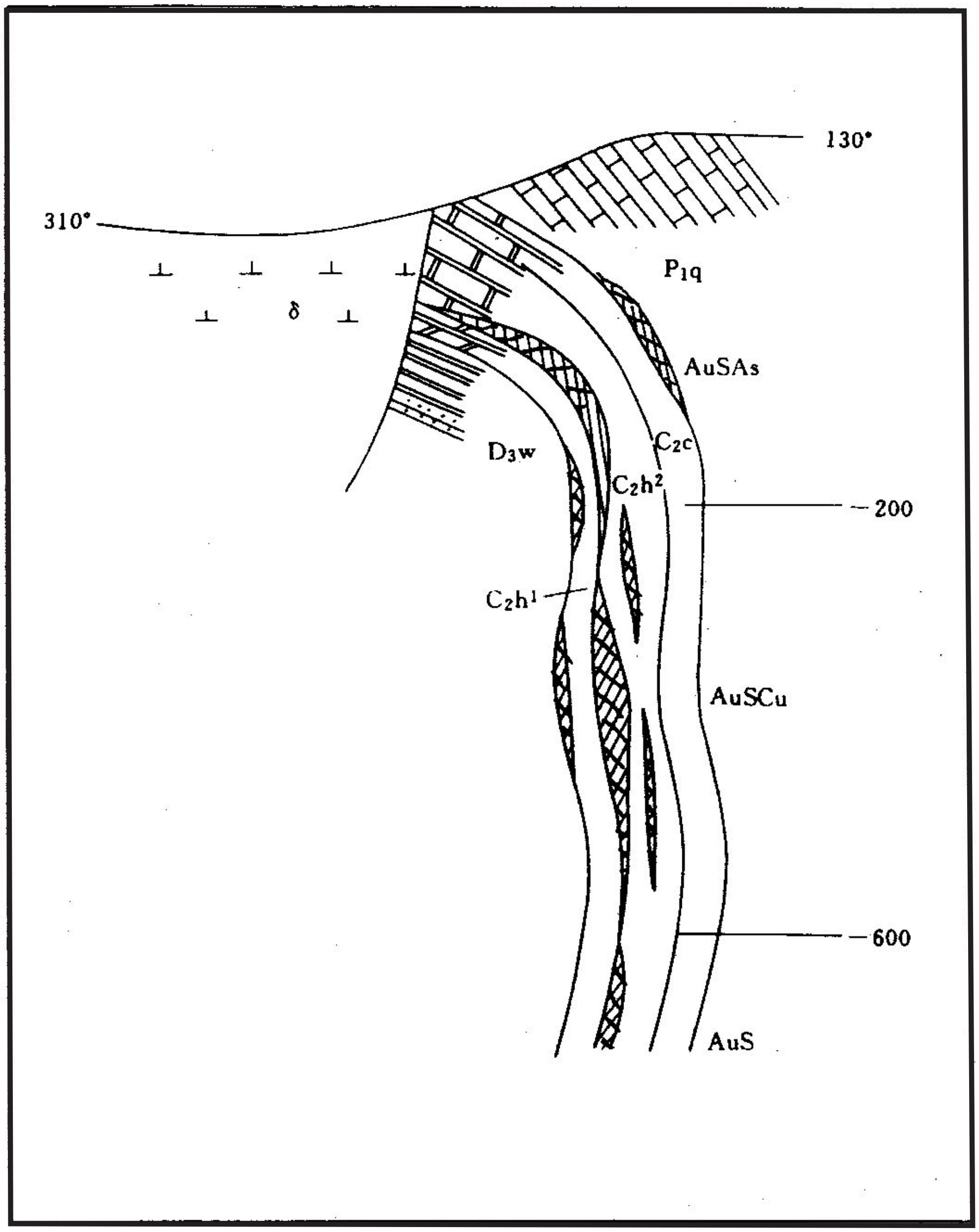


Figure 5-50. Schematic geologic cross section, looking northeasterly, of the Mashan Au deposit, Anhui Province, Middle-Lower Yangtze River area. Ore is confined to specific horizons in the Carboniferous rocks. Modified from the Non Ferrous Industrial Bureau and Team 812 of the East China Geological Exploration Bureau, Tongling (see also, Wang, B.H., 1996).



The Synthetical Profile of Mashan Au Deposit

P_{1q}--limestone of Qixia formation C_{2c}--marble of Chuanshan formation

C_{2h}^{2}--marble of Huanglong formation C_{2h}^{1}--dolomitic marble of Huang formation

D_{3w}--sandstone & shale of Wutong formation δ-diorite Au ore body

Figure 5-51. Cross section through the Mashan Au deposit, Middle-Lower Yangtze riverarea, Anhui Province. Modified from Wang, B.H. (1996).

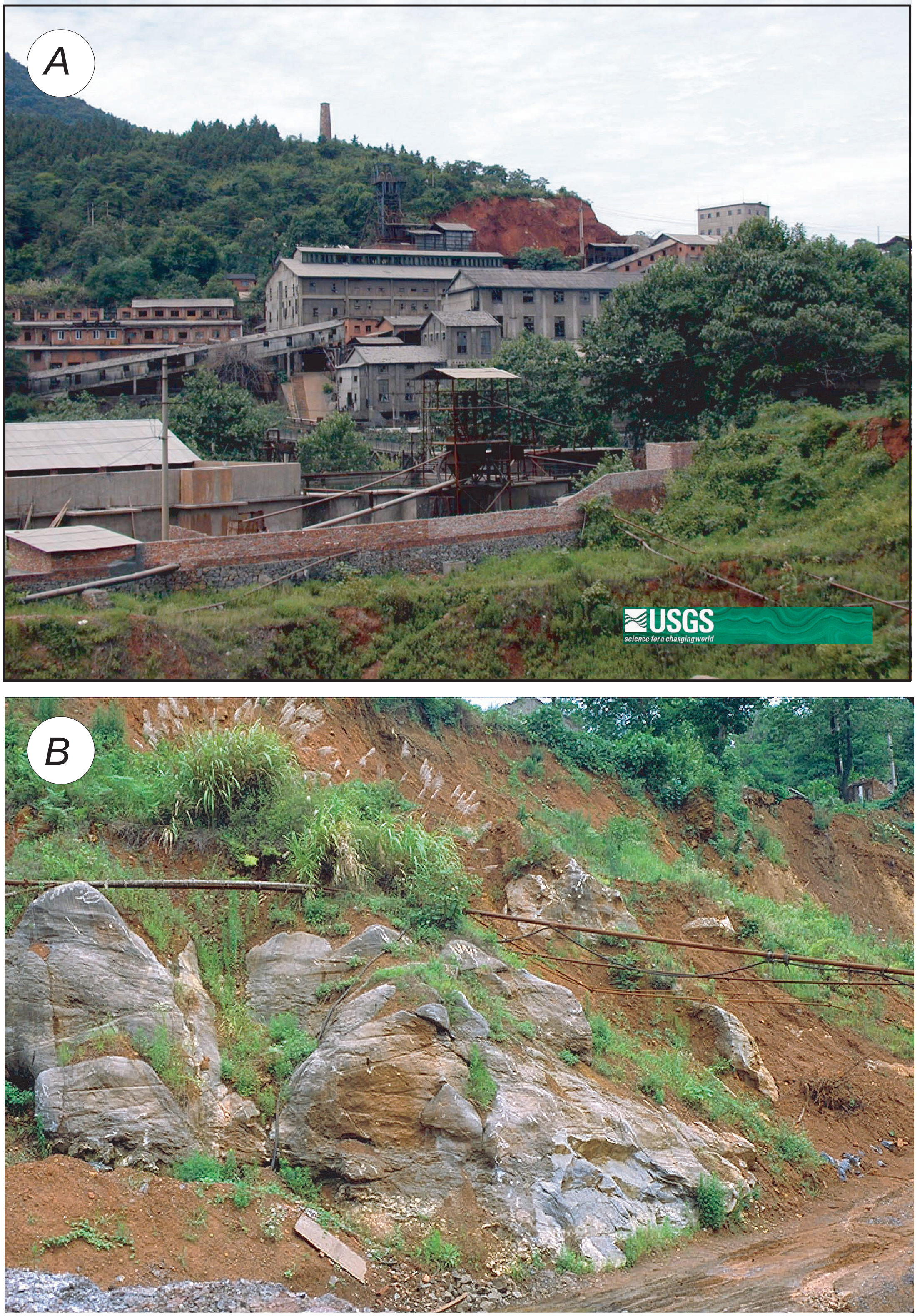


Figure 5-52. Photographs of the Mashan Au deposit area, Anhui Province, Middle-Lower Yangtze River area. (*A*) Mill complex in foot wall of deposit. Note smelter stack at skyline. (*B*) Footwall Devonian dolomite approximately 50 m from main lode.

The Mashan Au deposit mainly is hosted in contact-metamorphosed Carboniferous series and Upper Devonian series calcareous sedimentary rocks. Limestone and dolomite and lesser sandstone are the main host rocks. The main host horizons are the marbles of the Chuanshan (C_2c) and Huanglong (C_2h^2) Formations and dolomites of the Huanglong (C_2h^1) Formation. Hanging wall limestone rocks of the coal-bearing Permian Qixia Formation (P_1g) locally contain small Cu–rich ore pods. The deposit lies above foot wall sandstone and shale of the Devonian Wutong Formation (D_3w) and is overlain by Triassic limestone (T_1h) (fig. 5-52*B*).

Hornfels, marble, and skarn are the most common alteration types and form a zone approximately 1,400 m long and 50 to 100 m wide. Skarn is most common in Permian limestone rocks proximal to the Mashan diorite. Carboniferous host rocks contain few skarn minerals, where assemblages instead are abundant marble and hornfels (figs. 5-54 and 5-55). Textures between marble wall rock and sulfide minerals show centimeter-scale sideritic reaction zones and crosscutting veinlets (fig. 5-54), suggesting that alteration continued after the marble formed. Detailed layering and complex folding is present in zones of massive sulfide. These detailed features also are compatible with emplacement of sulfide minerals prior to formation of the marble (fig. 5-55), similar to polymetallic replacement deposits described by Morris (1986) and Mosier and others (1986). Although regional metallogenic processes are assumed to be directly linked to intrusive activity, textures of ore minerals indicate possible paragenesis prior to or after contact metamorphism.

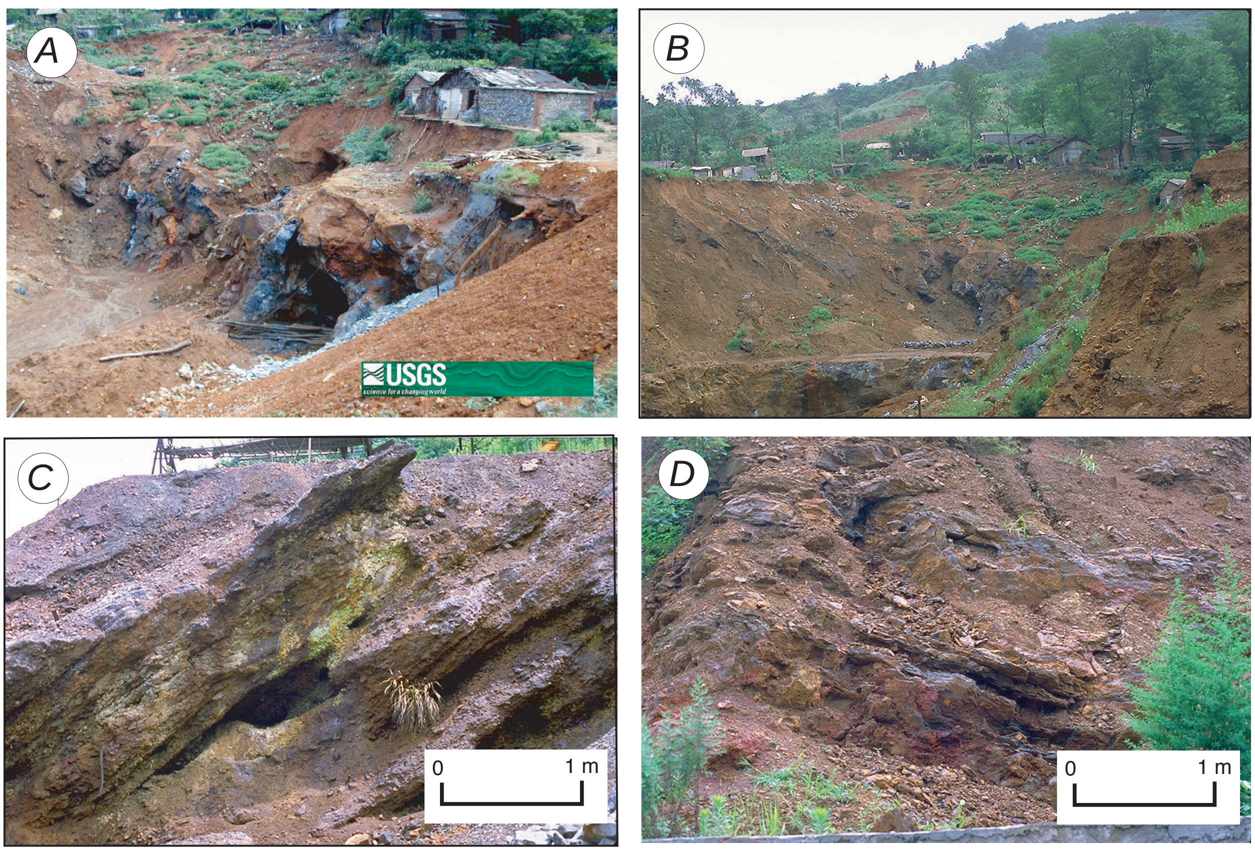


Figure 5-53. Photographs of gossanous outcrops of massive sulfide ores from the Mashan Au deposit, Anhui Province, Middle-Lower Yangtze River area. (*A*) Portal and excavations on gently driven strata. (*B*) Open pit showing soil profile and harder siliceous gossan (darker colors). (*C*) Layered, highly arsenical gossan outcrop. (*D*) Gossanous outcrop showing layering and bedding.

Ore-bearing minerals are pyrrhotite (41.5 volume percent), pyrite (24.1 volume percent), arsenopyrite (11.1 volume percent), electrum and native microscopic Au with local chalcopyrite, galena, and sphalerite. Main gangue minerals are quartz, calcite, chlorite, dolomite, and plagioclase (figs. 5-56, 5-57, 5-58, and 5-59). The ore mainly is in euhedral to subhedral, then anhedral grains and in colloform textures and also contains massive, disseminated, banded, and breccia textures. Pyrrhotite typically is massive with subhedral crystals and contains 1– to 4–cm-sized euhedral to subhedral crystals and blebs of pyrite (fig. 5-56). Many of the ores are banded with 0.5– to 2–cm-thick layers of alternating marble, quartz, marble, pyrite, and pyrrhotite (figs. 5-55 and 5-57). Arsenopyrite typically is euhedral, locally is massive, and forms in clumps and irregular masses (figs. 5-56, 5-58, and 5-59).

The Mashan Au deposit hypogene ores contain anomalous concentrations of As, Bi, Ag, Cu, Pb, and Zn with moderate concentrations of F. The ores generally have low concentrations of Tl and contains lower concentrations of Sb and Hg than the Xinqiao Au deposit, with which is shares most other similar geochemical, textural and geologic characteristics (Appendix IV). The anomalous geochemical suite is compatible with pluton-related, distal-disseminated sedimentary rock-hosted Ag–Au deposits and with polymetallic replacement deposits. Values of ´^{34}S for pyrrhotite and pyrite range between +3.8 to +7.6 0 and arsenopyrite has higher ´^{34}S values of between +7.7 and +9.5 % (table 5-1).

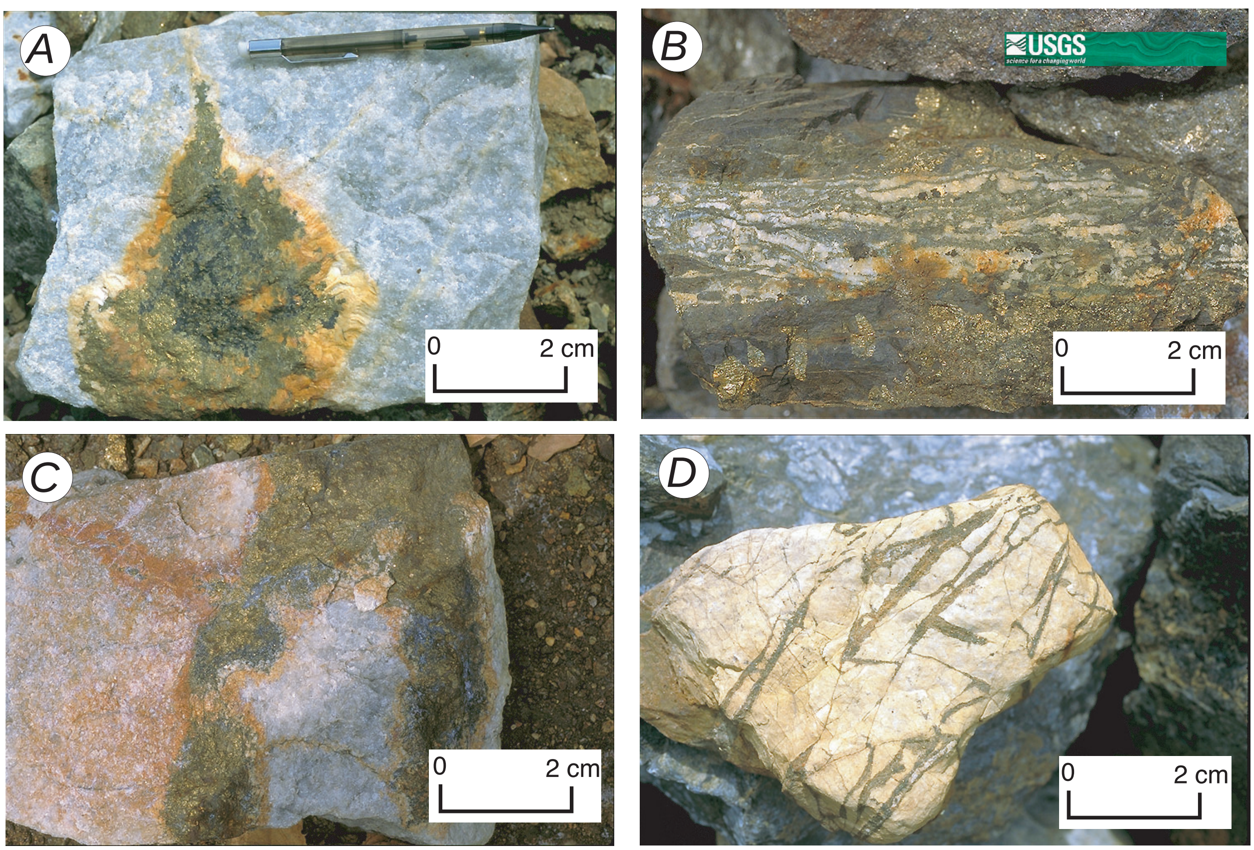


Figure 5-54. Photographs of relations among sulfide pods and marble wall rock, Mashan Au deposit, Anhui Province, Middle-Lower Yangtze River area. (*A*) Pyrite bleb invading marble with siderite halo. (*B*) Interlayered marble, coarse- and fine-grain pyrite along bedding plane. (*C*) Inclusion of marble along zoned chalcopyrite and pyrite mass with Fe-stains in marble. (*D*) Open space filling of sulfide mineral in joints in bleached calcareous mudstone.

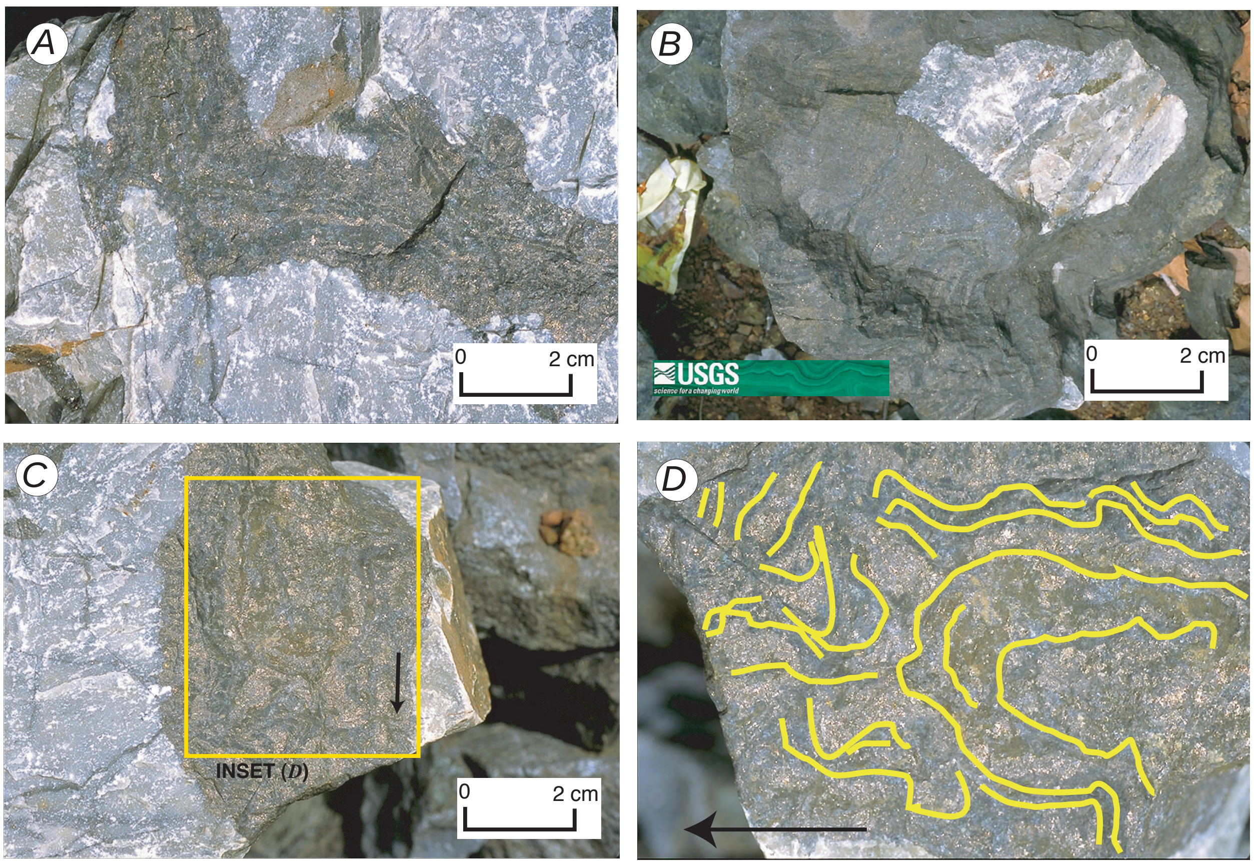


Figure 5-55. Photographs of hand-specimens of folded sulfide ores and relation to massive marble, Mashan Au deposit, Anhui Province, Middle-Lower Yangtze River area. (*A*) Layered pyrrhotite and pyrite with dolomite in massive marble. (*B*) Folded, layered and banded pyrite and pyrrhotite surrounding massive white marble that appears to have conformable layering with sulfide minerals. (*C*) Complex folding in sulfide minerals encased in marble. (*D*) Inset from C with form lines. Arrows show mutual orientation.

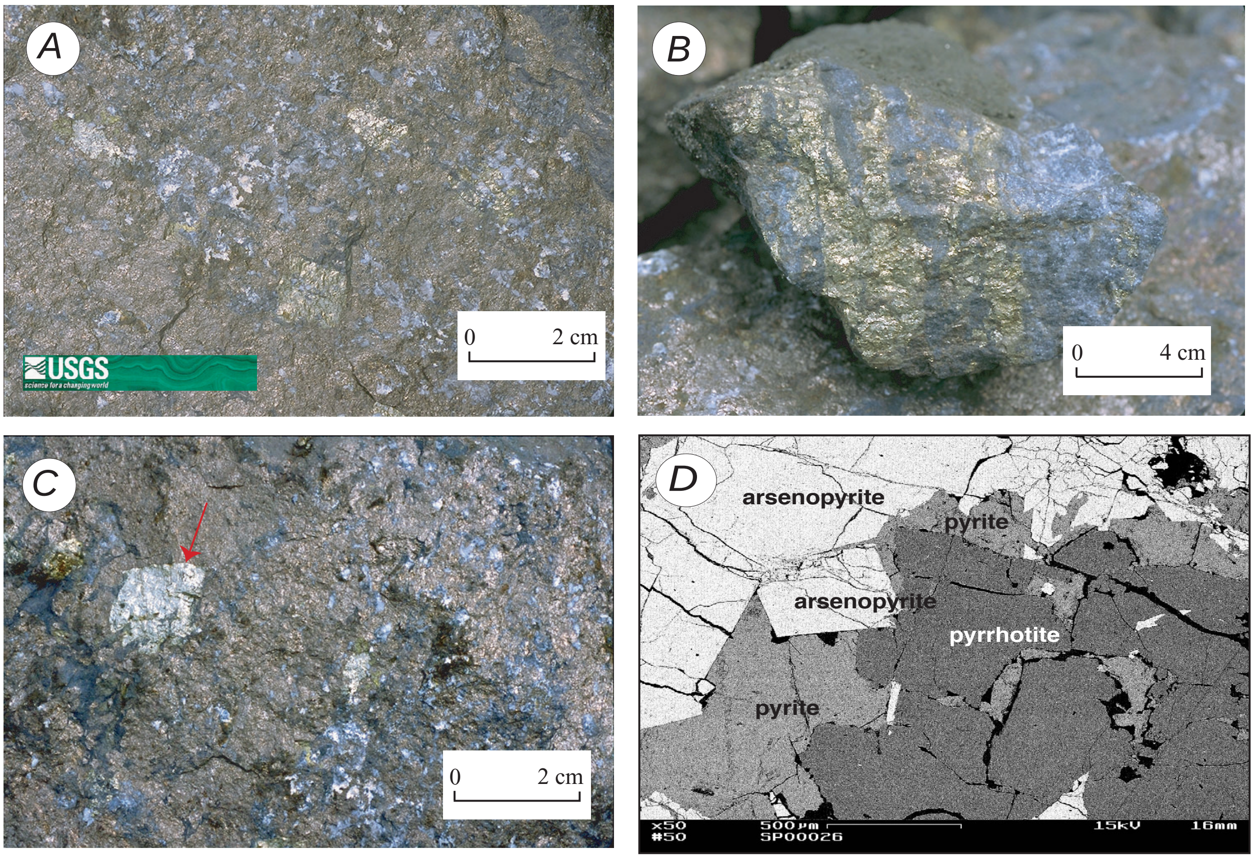


Figure 5-56. Photographs and scanning electron microscope back scatter image of examples of sulfide-rich hypogene ore from the Mashan Au deposit, Anhui Province, Middle-Lower Yangtze River area. (*A*) Massive pyrrhotite with crude layering shown as streaked calcite (former bedding?) and large porphyroblastic crystals of pyrite. (*B*) Layering of pyrite and marble. (*C*) Massive pyrrhotite with large crystal of arsenopyrite at head of arrow. (*D*) Scanning electron microscope back scatter image showing textural interrelations among pyrrhotite, pyrite, and arsenopyrite.

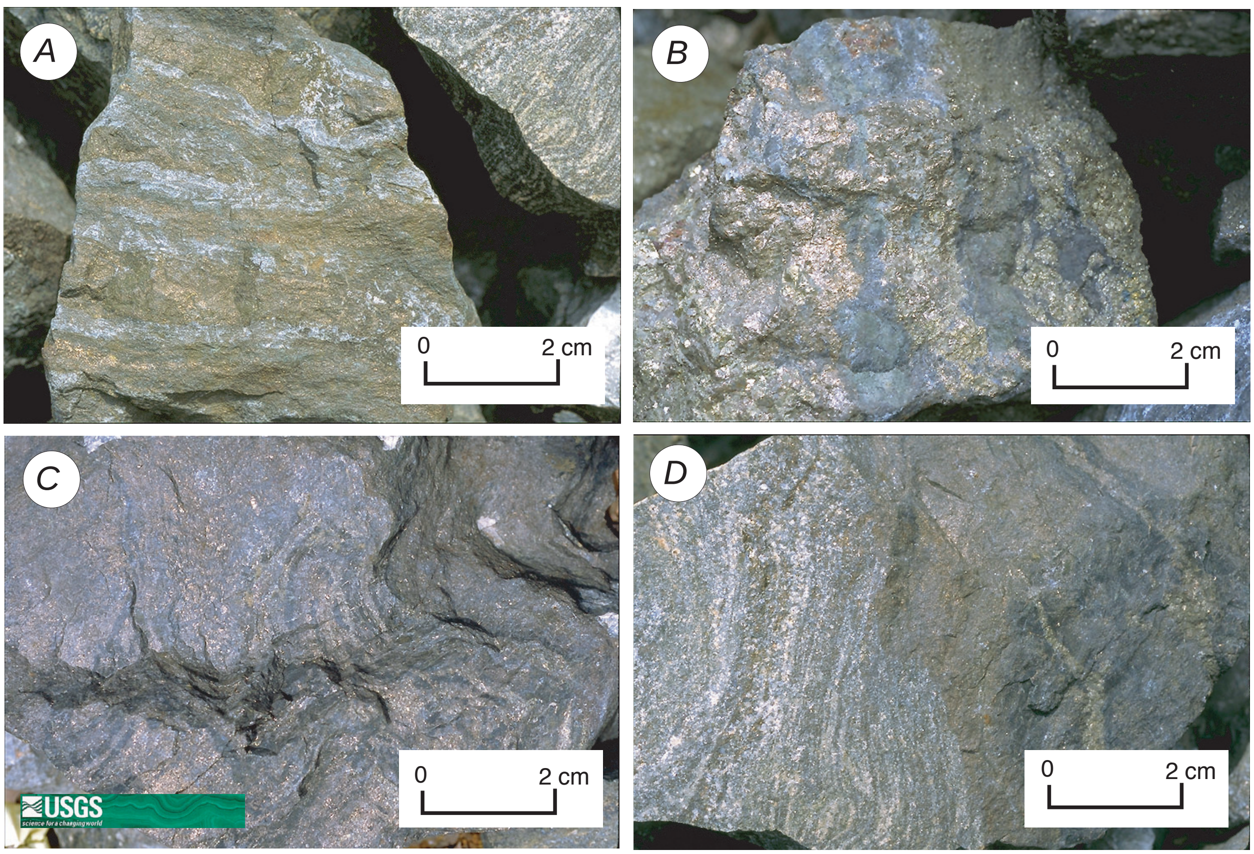


Figure 5-57. Photographs of examples of banding in sulfide ores from the Mashan Au deposit, Anhui Province, Middle-Lower Yangtze River area. (*A*) Layering of pyrite and chalcopyrite with dolomite and marble. (*B*) Mottled banding with crystalline dolomite and marble. (*C*) Fine layering and folding of pyrite layers. (*D*) Massive sulfide and sulfide veinlets acutely cross-cutting bedding layering.

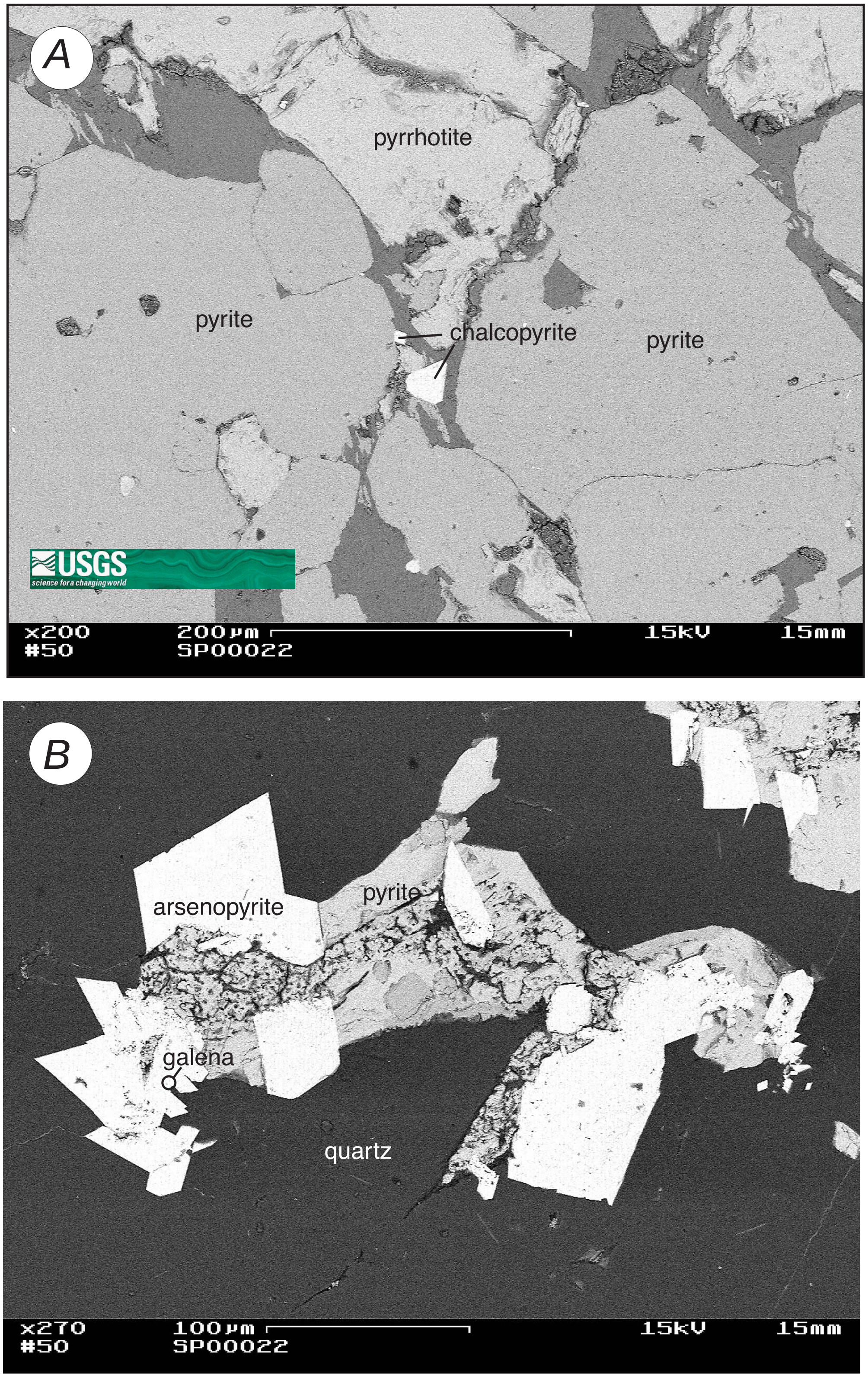


Figure 5-58. Scanning electron microscope back scatter images of sulfide ores from the Mashan Au deposit, Anhui Province, Lower Yangtze River area. (*A*) Pyrrhotite, pyrite and chalcopyrite; (*B*) Arsenopyrite, pyrite, galena, and quartz.

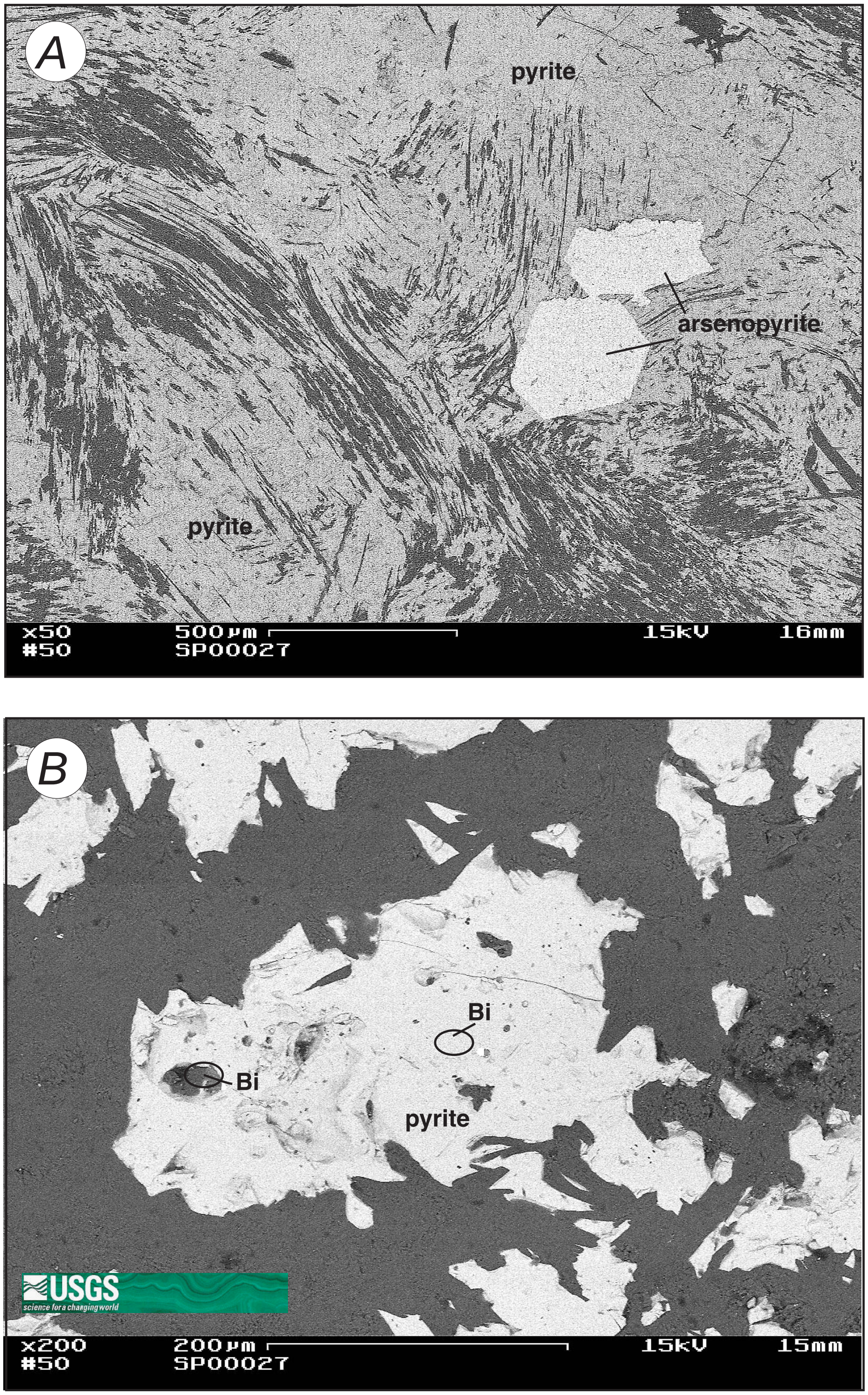


Figure 5-59. Scanning electron microscope backscatter image of sulfide ore from Mashan deposit, Anhui Province, Lower Yangtze River area. (*A*) Pyrite and arsenopyrite. Layers may be from original bedding. (*B*) Bismuth inclusions in pyrite grains.

Huangshiloashan Au deposit

The Huangshiloashan Au deposit is located at E. 117° 48’ 49’’and N. 30°53’50’’out side and 6 km away from the downtown of Tongling city, Anhui Province at an elevation of 210.8 m above sea level. Coal from Permian rocks and limestone from Triassic rocks are mined nearby. The deposit consists of 11 orebodies. The main orebody is tabular, 1,100 m long, 349 to 123 m wide, 1 to 17.82 m thick, and strikes NW at 390°, and dips southeast 113°at angles between 75 to 88°. The Huangshiloashan Au deposit is a medium-size Au deposit with Au reserve of 13.425 tonne Au (average grade 5.78 g/t Au), a pyrite ore reserve of 812,700 tonne (S grade 18.31 weight percent), an Fe ore reserve of 15,090,000 tonne (ore grade 30.03 weight percent), and a Ag reserve of 56.262 tonne (average grade 24.12 g/t Ag) (see also, Wang, B.H., 1996).

Orebodies at Huangshiloashan are more uniform and continuous than those at Mashan on the other limb of the Tongguanshan anticline (figs. 5-60 and 5-61). The mine is operated by the Gold Bureau of Tongling Country and employs 440 people (figs. 5-62, and 5-63). Underground workings are accessed through 300–m-deep shafts. Mine level workings are on 40– to 50–m-spaced levels and mining is from top down, employing a filling method and ore is hoisted in 1.5 tonne buckets. Mining mainly concentrates on the ore in the oxide gossanous zone, which

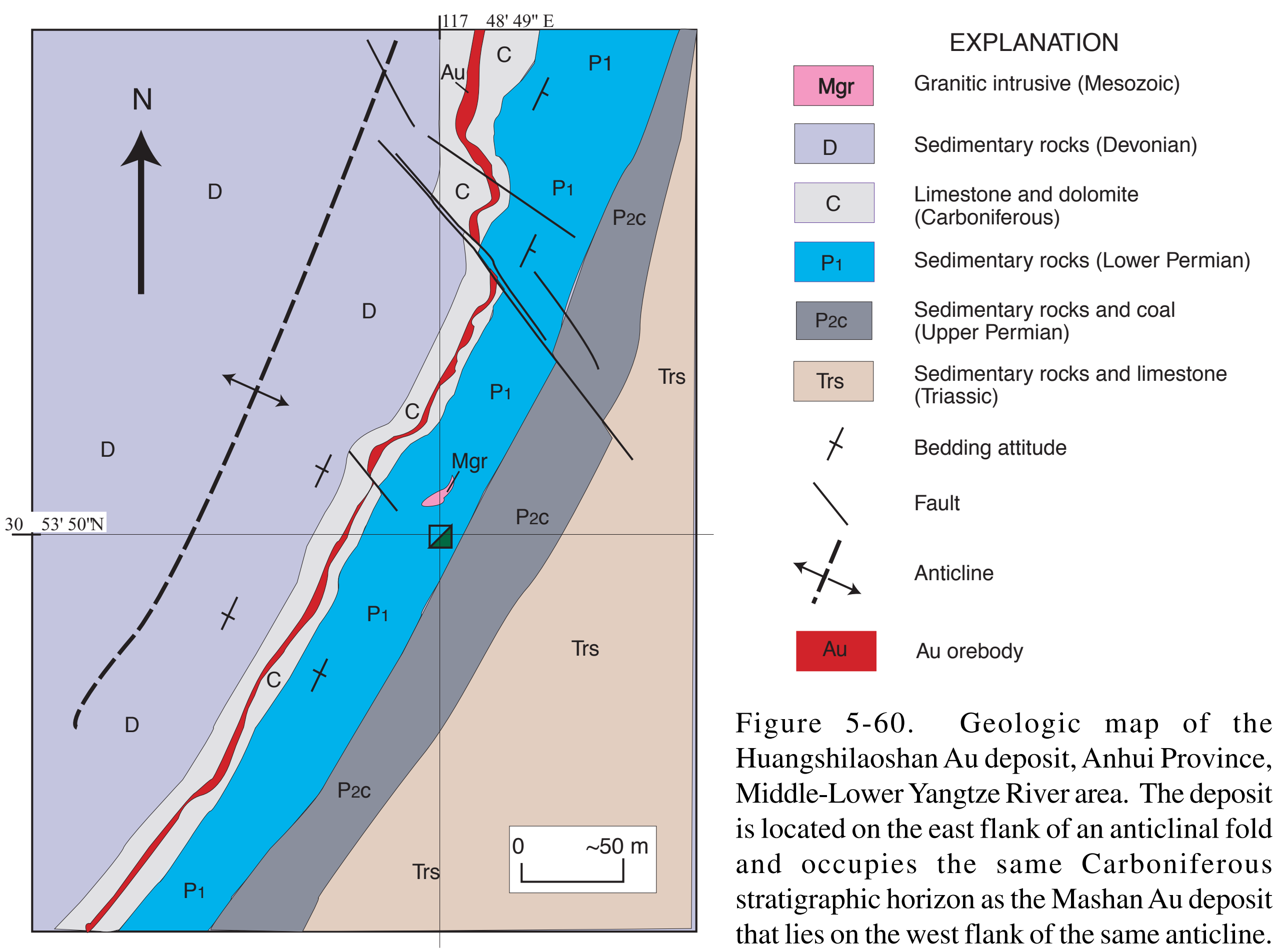


Figure 5-60. Geologic map of the Huangshilaoshan Au deposit, Anhui Province, Middle-Lower Yangtze River area. The deposit is located on the east flank of an anticlinal fold and occupies the same Carboniferous stratigraphic horizon as the Mashan Au deposit that lies on the west flank of the same anticline. Longitude and latitude are approximate. Modified from Gold Bureau of Tongling Country and Wang, B.H. (1996).

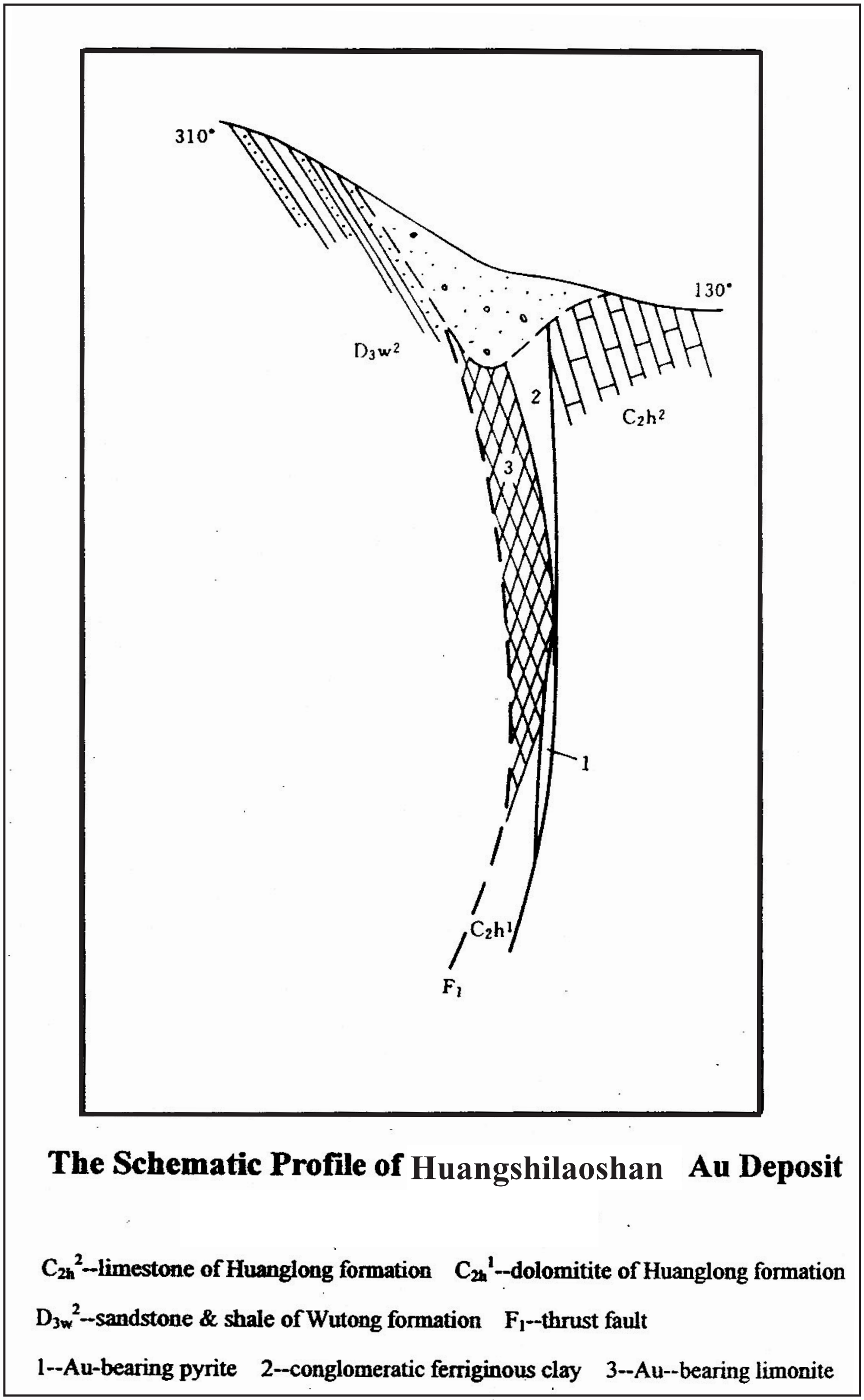


Figure 5-61. Cross section through the Huangshilaoshan Au deposit, Middle-Lower Yangtze River area, Anhui Province. Modified from Wang, B.H. (1996).

Figure 5-62. Photographs of Huangshilaoshan Au deposit mine area, Anhui Province, Middle-Lower Yangtze River area. (*A*) Mine mill area in foreground and limestone mines in Triassic sedimentary rocks in the background. (*B*) Mill area with rail system to unload ore. (*C*) Underground mine workers coming off shaft, walking from workplace. (*D*) Unloading gossanous ore and sulfide ore to be sorted.

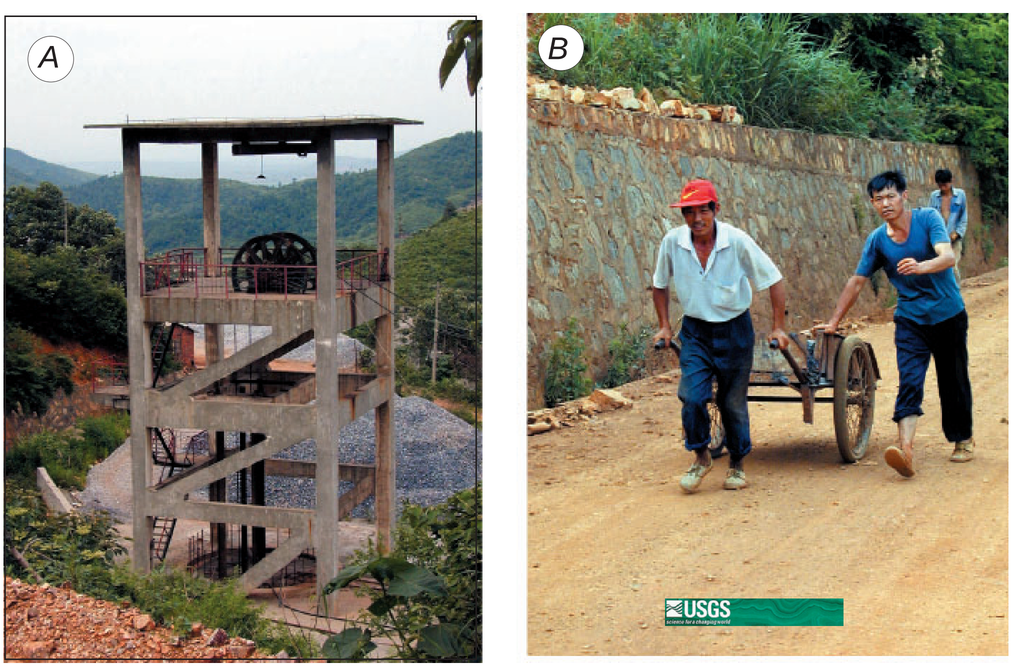


Figure 5-63. Photographs of Huangshilaoshan Au deposit mine area. (*A*) Shaft in hanging wall of ore horizon. (*B*) Miners transporting supplies along haul road.

represents about 90 percent of mill feed. Run of mine ore is about 70 percent gossan and 30 percent sulfide ore. The level of the oxide zone varies in depth. Both oxide and sulfide ore are processed by cyanide and carbon-in-pulp methods after grinding to about 0.074 mm. Mill recovery is 85 to 95 percent. Production rates are 700 kg Au per year.

The Huangshiloashan Au deposit is part of a group of Cu and Au deposits located in a regional-scale fold belt of the Guichi-Fanchang fault depression, along the Middle-Lower Yangtze syncline, in the Yangtze peneplatform. On a district scale, the deposit is part of an ore field along the northeast limb of the Tongguanshan anticline in the Tongling fold complex and occupies the same stratigraphic horizon as the Mashan Au deposit on the other limb of the anticline.

The Huangshiloashan Au deposit is hosted in steeply east-dipping middle Carboniferous and upper Devonian sedimentary, calcareous rocks. The host rocks are limestone, arenaceous shale, mudstone and dolomite. The main host horizons are the dolomitic Huanglong Formation (C_2h^1), similar to the Mashan Au deposit (figs. 5-60 and 5-61). Marble, sericite, and silica are present along a prominent 1,800–m-long alteration zone in this horizon (fig. 5-60).

Ore-bearing minerals in the oxide zone are hydrogoethite (55 volume percent), hydrohematite (10 volume percent), pyrolusite and (or) psilomelane (2 volume percent), minor pyrite, and microscopic native Au. Gangue minerals are kaolinite, illite, calcite, quartz, and dolomite. Oxide ore has a typical gossanous texture and is typified by red, maroon and yellow granular, acicular, pseudomorphic (boxworks), as well as inclusion, earthy powder, massive, porous, and breccia textures (fig. 5-64). Hypogene ores contain massive, stratabound zones of pyrite, arsenopyrite, pyrrhotite with local chalcopyrite, sphalerite, galena, and Bi minerals (fig. 5-65 and 5-66).

The Huangshiloashan Au deposit has geochemically anomalous concentrations of F, As, Bi, Ag, Cu, Pb, and Zn in the hypogene ores, similar to the Xinqiao and Mashan gossan Au deposits. The gossanous ores also are anomalous in W, Sb, and Hg (Appendix IV), suggesting that these elements may be concentrated in the oxide zone ore or may possibly represent residual concentration of these elements in the high grade Au ores. The ores from Huangshiloashan have negative pyrite and pyrrhotite $\delta^{34}S$ values of –4.6 to –9.3 ‰ (table 5-1), which sharply contrast to the positive $\delta^{34}S$ values from the adjacent Mashan, Tongguanshan, and Xinqiao deposits (see also, Ge, C.H. and others, 1990).

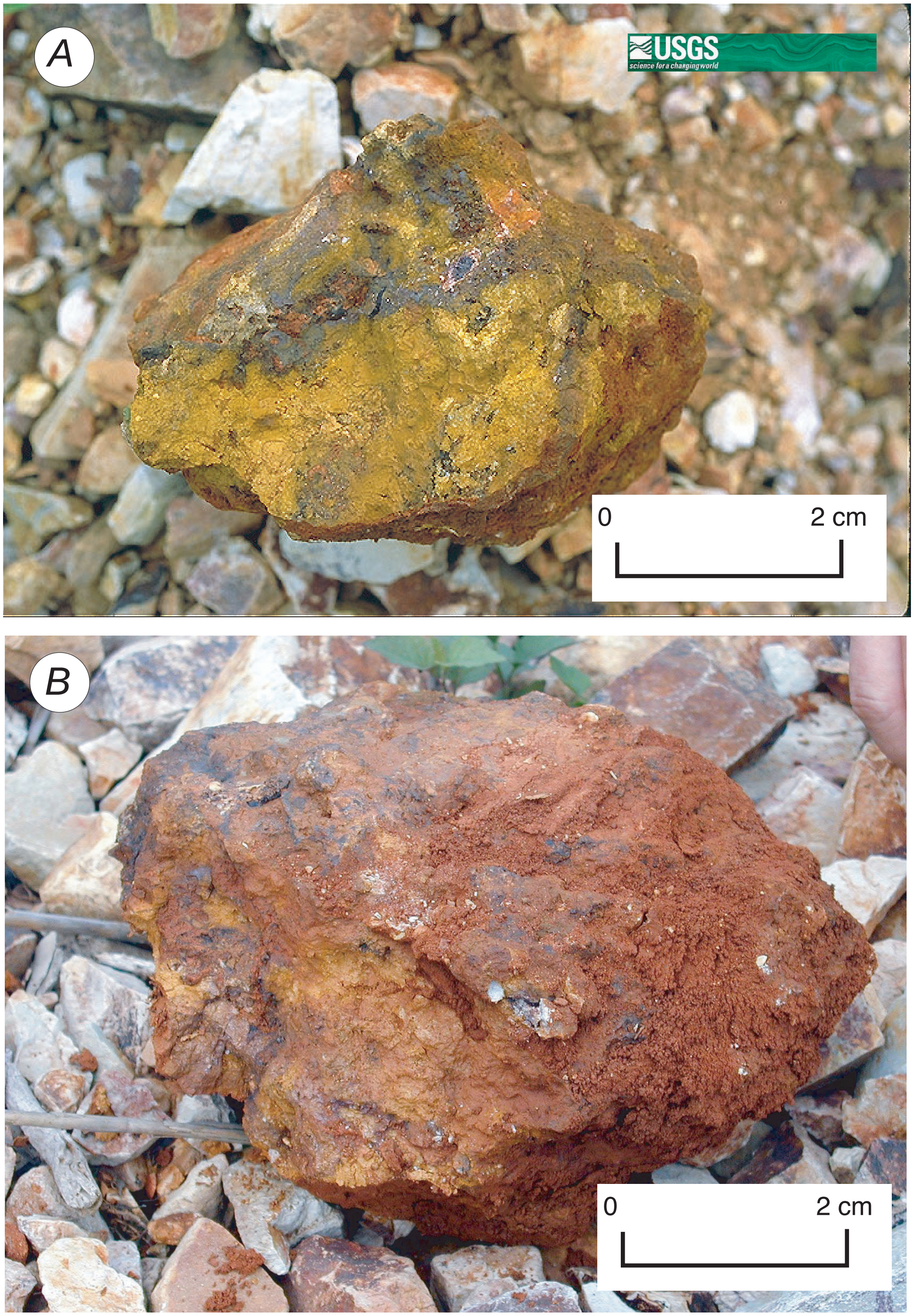


Figure 5-64. Photographs of gossanous ores from the Huangshilaoshan Au deposit, Anhui Province, Middle-Lower Yangtze River area. (*A*) Yellow, earthy hematitic gossan. (*B*) Maroon, clay-rich gossan.

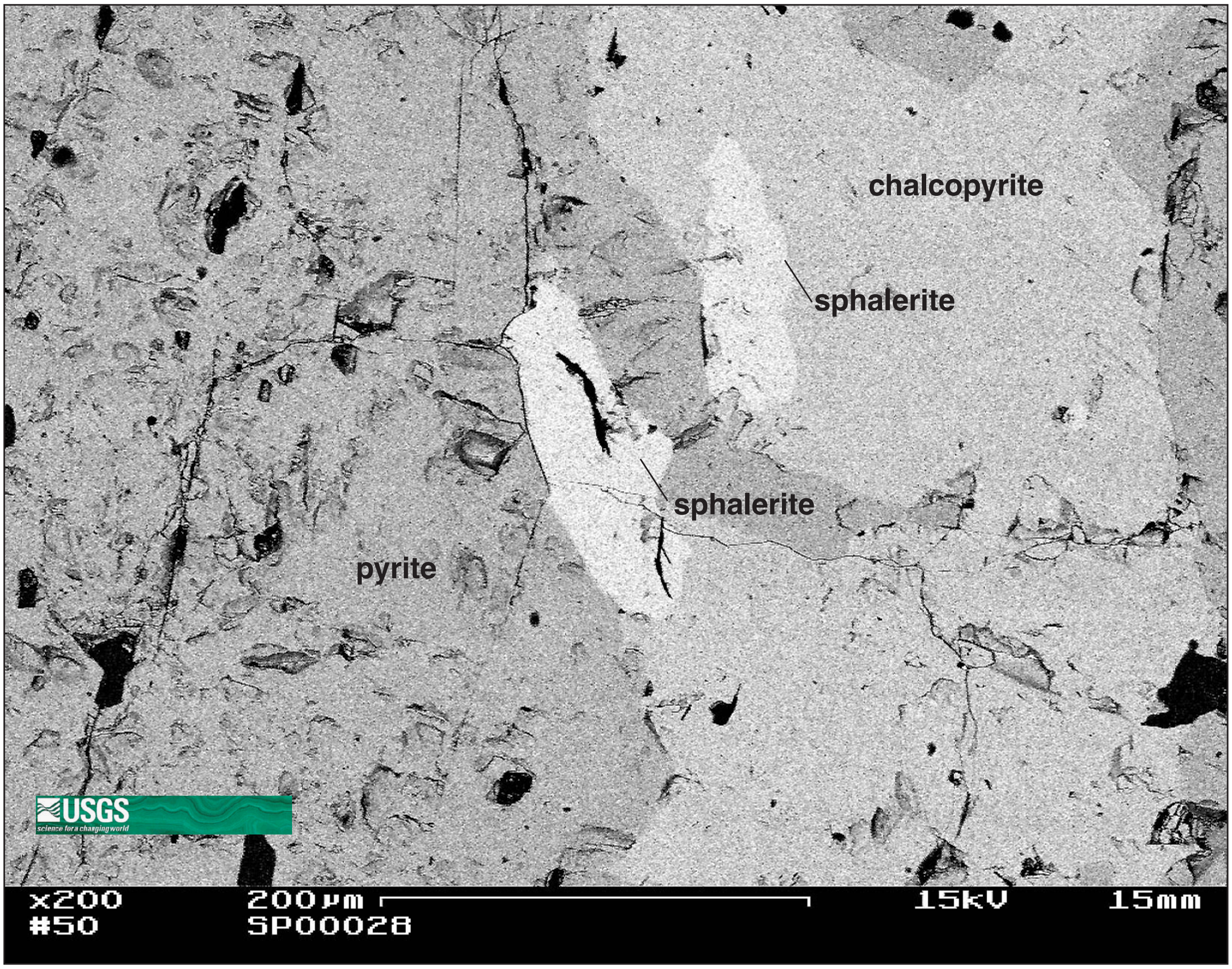


Figure 5-65. Scanning electron microscope back scatter image of polymetallic sulfide ore, Huangshilaoshan Au deposit, Anhui Province, Middle-Lower Yangtze River area, showing sphalerite grains at contact between chalcopyrite and pyrite.

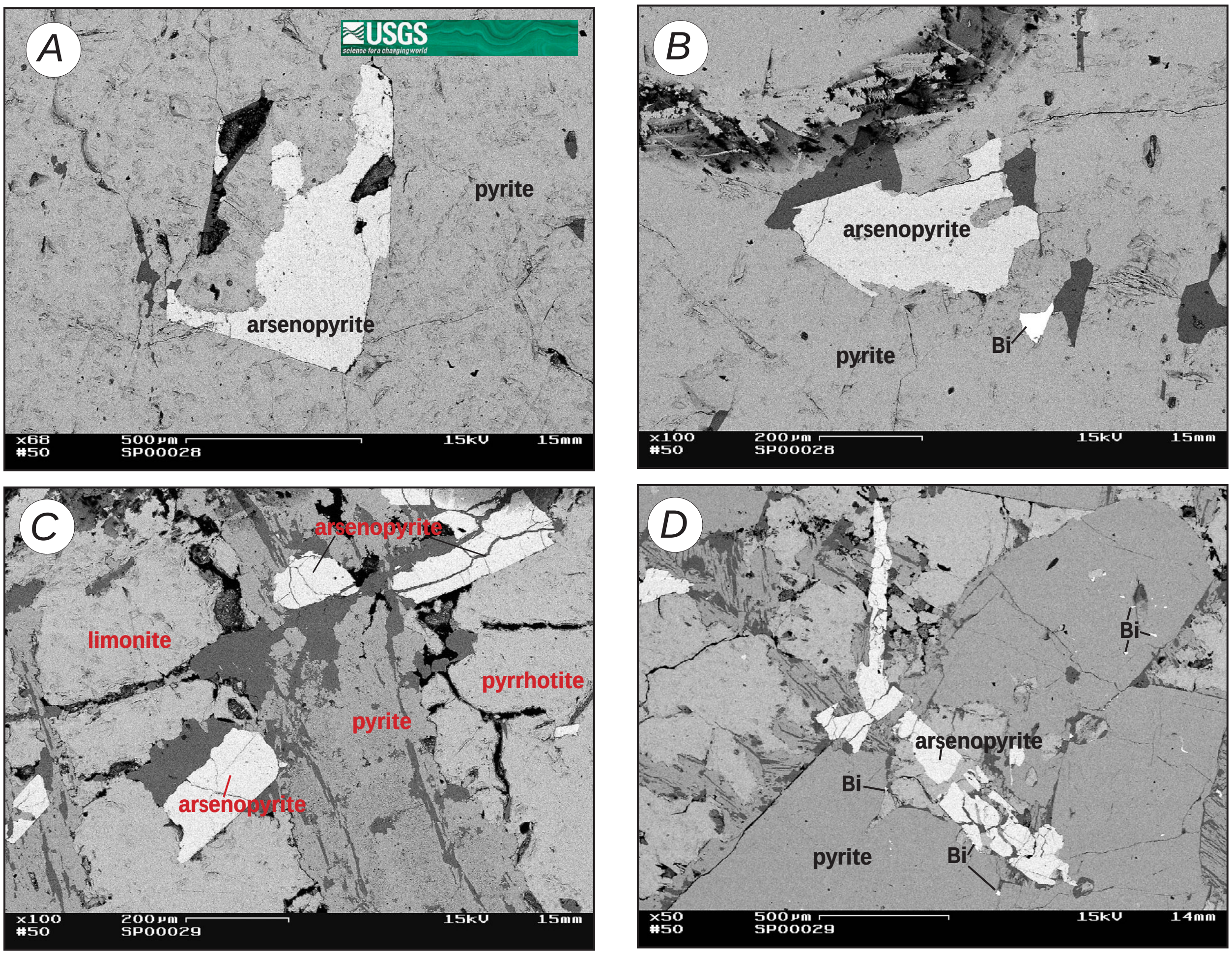


Figure 5-66. Scanning electron microscope back scatter images of sulfide ores from Huangshilaoshan Au deposit, Anhui Province, Middle-Lower Yangtze River area. (*A*) Arsenopyrite grain in massive pyrite. (*B*) Arsenopyrite and bismuth grains in pyrite. (*C*) Pyrite, pyrrhotite, and limonite (supergene) with arsenopyrite disseminations. (*D*) Pyrite, arsenopyrite with bismuth growths and disseminations.

CONCLUSIONS

Pluton- or porphyry-related sedimentary rock-hosted Au deposits in the Lower-Middle Yangtze River area are distal-disseminated Ag–Au and Au-rich polymetallic replacement deposits. These deposits differ from the Carlin-type Au deposits, but are part of the sedimentary rock-hosted Au deposit family (fig. 1-11). They contain Ag and Au in disseminations, replacements, and stockworks of narrow quartz-sulfide veinlets and (or) Fe oxide-stained fractures in sedimentary rock, and they contain some diagnostic trace elements—specifically Zn, Mn, Cu, and Bi—which are consistent with many pluton-related deposits (Cox and Singer, 1992). Ores in the Middle-Lower Yangtze River area contain these minerals and elements and locally also contain celestite, fluorite, pyrrhotite, and arsenopyrite. Fluids involved in the generation of these deposits include a significant magmatic component (Li, Z.P. and Yang, W.S., 1989). The Middle-Lower Yangtze River area Au deposits have strong characteristics typical of polymetallic replacement or manto deposits, which are massive lenses of dense sulfide minerals in limestone, dolomite, or other soluble rocks near igneous intrusions (see also, Morris, 1986; Mosier and others, 1986).

Although many distal-disseminated Ag–Au and polymetallic replacement deposits are hosted by sedimentary rocks, they contain distinct features that differentiate them from Carlin-type Au deposits. For instance, many distal-disseminated Ag–Au deposits contain more Ag and base-metals than most Carlin-type Au deposits (Peters and others, 1996). The deposits are hosted in specific strata of lower Triassic sedimentary rocks in southeastern Hubei Province in Tonglushan-Daye area, and in upper Carboniferous silty limestone strata in Anhui Province in the Tongling area. Carlin-type Au deposits, however in the Middle-Lower Yangtze River area, such as the Zhanghai Au deposit, are hosted in black Silurian phyllite and shale.

The link between Carlin-type Au deposits, such those in the Dian-Qian-Gui and Qinling fold belt areas and plutonic rocks is not demonstratable, but a direct relation of the deposits to igneous rocks is present in the Middle-Lower Yangtze River area. In Nevada, igneous activity followed and accompanied tectonic events in the Mesozoic and Tertiary and produced plutons and Tertiary volcanic rocks around many of the known areas of sedimentary rock-hosted Au deposits. There could be a link between pluton-related deposits and Carlin-type Au deposits.

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REFERENCES

Albino, G.V., 1993, Application of metal zoning to gold exploration in porphyry copper systems by B.K. Jones: comments: Journal of Geochemical Exploration, v. 48, no 3, p. 359–366.

Arehart, G. B., 1996, Characteristics and origin of sediment-hosted gold deposits: a review: Ore Geology Reviews, v. 11, p. 383–403.

Berger, B. R., 1986,–Descriptive model of carbonate-hosted Au–Ag, *in* Cox, D. P., and Singer, D. A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 175.

Butts, C.R.M., 1989, Genesis of supergene gold deposits in the lateritic regolith of the Yilgarn Block, Western Australia, *in* Keays, R.R., Ramsay, R.H., and Groves., D.I., eds., The Geology of Gold Deposits, the Perspective in 1988: Economic Geology Monograph 6, p. 460–470.

Chen Peiliang, 1996a,–The iron-copper-gold metallogenic regularities of the lower-middle reaches of the Yangtze River, , *in* Wang, Yongji, Qin, You-yu, and Chen, Peiliang, eds., Geology of iron, copper, gold, and silver mineral resources in the middle and lower reaches of the Yangtze River: Press House of Metallurgical industry, Beijing, p. 19–34. (in Chinese).

Chen, Peiliang, 1996b, Geological characteristics of gold deposits in middle and lower reaches of the Yangtze river, *in* Wang, Yongji, Qin, You-yu, and Chen, Peiliang, eds., Geology of iron, copper, gold, and silver mineral resources in the middle and lower reaches of the Yangtze River: Press House of Metallurgical industry, Beijing, p. 97–101 (in Chinese).

Cox, D.P, 1992, Descriptive and grade and tonnage models of distal–disseminated Ag–Au, *in* Bliss, J.D., ed., Developments in deposit modeling: U.S. Geological Survey Bulletin 2004, p. 19–22.

Cox, D.P., and Singer, D.A, 1990, Descriptive and grade-tonnage models for distal-disseminated Ag–Au deposits: A supplement to U.S. Geological Survey Bulletin 1693: U.S. Geological Survey Open–File Report 90–282, 7 p.

———1992, Grade and tonnage model of distal-disseminated Ag–Au, *in* Bliss, J.D., ed., Developments in mineral deposit modeling: U.S. Geological Survey Bulletin 2004, p. 20–22.

Committee for Determining and Approving Terminology in Geology, 1993, Terminology of Geology: Beijing Press House of Sciences, Beijing, 226 p. (in Chinese).

Cun, Gui, 1995, Typical Gold Deposits in China: Geological Press, Beijing, 466 p., (in Chinese).

Dean, W.E., Bostick, W.H., Bartel, A.J., Brandt, E.L., Davis, T.A., Doughten, M., Gent, C.A., Juanaraja, S.R., Libby, B., Malcolm, M.J., Robb, E.C., Taggert, J.E., Threlkeld, C.N., Voletich, A.K., Cunningham, C.G., Ashley, R. P., and Chou I-M, 1988, Data of geochemistry and thermal maturation of sedimentary rock-hosted disseminated gold deposits and associated rocks, southwestern Guizhou Province, People's Republic of China: U.S. Geological Survey Open–File Report 88–271, 22 p.

Deng, S., Shen, Q., Sun, P., and Tu, L., 1986, Metamorphic Map of China with explanatory text: Geological Publishing House, Beijing, 162 p., 1 sheet, [1:4,000,000].

Fan, Powfoong, 1984, Geologic setting of selected copper deposits of China: Economic Geology, v. 79, p. 1,785–1,795.

Ge, Chaohua, Sun, Haitan, and Zhou, Taihe, 1990, Copper deposits of China, *in* Liu, Nailong, ed., Mineral Deposits of China: Geological Publishing House, v. 1, p. 1–106.

Hill, R.H., Adrian, B.M., Bagby, W.C., Bailey, E.A., Goldfarb, R.J., and Pickthorn, W.J., 1986, Geochemical data for rock samples collected from selected sediment-hosted disseminated precious metal deposits in Nevada: U.S. Geological Survey Open–File Report 86–107, 30 p.

Hitchborn, A.D., Arbonies, D.G., Peters, S.G., Connors, K.A., Noble, D.C., Larson, L.T., Beebe, J.S., and McKee, E.H., 1996, Geology and gold deposits of the Bald Mountain Mining District, Whitepine County, Nevada, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera, Symposium Proceedings, Geological Society of Nevada, Reno/Sparks, Nevada, April, 1995, p. 505–546.

Hofstra, A.H., and Cline, J.S., 2000, Characteristics and models for Carlin-type gold deposits, *in* Hagemann, S. G., and Brown, P. E., eds., Gold in 2000: Reviews in Economic Geology, v. 13, p. 163–220.

Hsu, K.J., Li, J., Chen, H., Wang, W., Sun, S., and Stengor, A. M. C., 1990, Tectonics of South China: Key to understanding west Pacific geology: Tectonophysics, v. 183, p. 9–40.

Huang, Y., Bi, Y.F., Jen, K.C., Liu, Y.E., and Zhou, Y.P., 1957, Daye iron deposit: Acta Geologica Sinica, v. 37,p. 191–202 (in Chinese).

Ji, Xian, and Coney, P. J., 1985, Accreted Terranes of China, *in* Howell, D.G., Tectonostratigraphic Terranes f the Circum-Pacific Region: Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, no. 1, p. 349–361.

Kuo, T., 1957, The skarn type copper ore deposits of the Middle-Lower Yangtze, China: Acta Geologica Sinica, v. 37, p. 1–10.

Li, Zhiping and Yang, Wensi, 1989, Relation between magmatism and gold mineralization in south Anhui province: Contributions to Geology and Mineral Resource Research, v. 4, no 2, p. 45–53, (in Chinese).

Li, Zhiping, and Peters, S.G. 1998, Comparative Geology and Geochemistry of Sedimentary-Rock-hosted (Carlin-type) Gold deposits in the People's Republic of China and in Nevada, USA: USGS Open-File Report 98-466, 160 p. (CDRom, v. 1.1 with data base), http://geopubs.wr.usgs.gov/open-file/of98-466/. v. 1.2 updated May, 2000, v. 1.3, March, 2001.

Liu, Bingguang and Yeap, E.B., 1992, Gold deposits of China: Newsletter of the Geological Society of Malaysia, v. 18, no. 6, p. 291–293.

Liu, X, Chang, and Wu, Y., 1988, Metallogenic conditions and regularities in the Middle and Lower Reaches of the Chunjiang river: Acta Geologica Sinica, v. 62, p. 167–177.

Margolis, Jacob, 1997, Gold paragenesis in intrusion-marginal sediment-hosted gold mineralization at Eureka, Nevada, *in* Vikre, Peter, Thompson, T.B., Bettles, K., Christensen, Odin, and Parratt, R., eds., Carlin-type Gold Deposits Field Conference: Economic Geology Guidebook Series, vol. 28, p. 213–222.

Mosier, D.L., Morris, H.T., and Singer, D.A., 1986, Grade and tonnage model polymetallic replacement deposits, *in* Cox, D.P., and Singer, D.A. eds., Mineral Deposit Models: U.S. Geological Survey Bulletin 1693, p. 101–104.

Morris, H.T., 1986, Descriptive model of polymetallic replacement deposits, *in* Cox, D.P., and Singer, D.A. eds., Mineral Deposit Models: U.S. Geological Survey Bulletin 1693, p. 99–100.

Ministry of Geology and Mineral Resources, 1985, Legend of Regional Geologic and Mineral Resources Investigation [1:5,000]: Geological Press House, Beijing, 274 p. (in Chinese).

Peters, S. G., Nash, J. T., John, D. A., Spanski, G. T., King, H. D., Connors, K. A., Moring, B. C., Doebrich, J. L., McGuire, D. J., Albino, V. J., Dunn, V. C., Theodore, T. G., And Ludington, S., 1996, Metallogenic Mineral Resources in The U. S. Bureau of Land Management's Winnemucca District and Surprise Resource Area, Northwest Nevada And Northeast California: U. S. Geological Survey Open–File Report 96–712, 147 p.

Peters, S.G., Ferdock, G.C., Woitsekhowskaya, M.B., Leonardson, Robert, and Rahn, Jerry, 1998, Oreshoot zoning in the Carlin-type Betze orebody, Goldstrike Mine, Eureka County, Nevada: U.S. Geological Survey Open–File Report 98-620, 49p.

———2000, Syndeformational Oreshoot Zoning in the Carlin-type Betze Orebody, Goldstrike Mine, Eureka County, Nevada: Dizhi Zhao Kuang Lan Chong, (Contributions to Geology and Mineral Resources Research), Part 1, No.1, 2000, 1-49 p., Part 2 No. 15, No. 2, p. 115-132, (in Chinese). [Available on Internet: www.chinajournal.net.cn].

Qi, Xue-xiang, 1996, The characteristics of Mesozoic magmatic rock in the middle and lower reaches of Yangtze river and its relation to metallization, *in* Wang, Yongji, Qin, You-yu, and Chen, Peiliang, eds., Geology of iron, copper, gold, and silver mineral resources in the middle and lower reaches of the Yangtze River: Press House of Metallurgical industry, Beijing, p. 35–50. (in Chinese).

Rei, Rongful, Wang, Ping'an, and Peng, Cong, 1999, Deep tectonic processes and super accumulation of metals related to granitoids in the Nanling Metallogenic Province, China: Acta Geologica Sinica, v. 73, no. 2, p. 181–192.

Ressel, M.W., Noble, D.C., Heizler, M. T., Volk, J. A., Lamb, J .B., Park, D. E., Conrad, J. E., and Mortensen, J.K., 2000a, Gold–mineralized Eocene dikes at Griffin and Meikle: bearing on the age and origin of deposits of the Carlin trend, Nevada, *in* Cluer, J.K., Price, J.G., Struhsacker, E.M., Hardyman, R.F., and Morris, C.L., eds., Geology and Ore Deposits 2000: the Great Basin and Beyond: Geological Society of Nevada symposium Proceedings, May 15–18, 2000, p. 79–101.

Ressel, M.W., Noble, D.C., Henry, C.D., and Trudel, W.S., 2000b, Dike-hosted ores of the Beast deposits and the importance of Eocene magmatism in gold mineralization of the Carlin Trend, Nevada: Economic Geology, v. 95, no. 7, p. 1,417–1,444.

Sawkins, F.J, 1983, Metal deposits in relation to plate tectonics: New York, Springer Verlag, 325 p.

Sillitoe, R.H., 1988, Gold and silver deposits in porphyry systems, *in* Schafer, R.W., Cooper, J.J., and Vikre, P.G., eds., Bulk-mineable precious metal deposits of the western United States: Reno, Nevada, Geological Society of Nevada, April, 1987, Symposium Proceedings, p. 233–257.

Sillitoe, R.H., 2001, Gold-rich porphyry deposits: descriptive and genetic models and their role in exploration and discovery, *in* Hagemann, S. G., and Brown, P. E., eds., Gold in 2000: Reviews in Economic Geology, v. 13, p. 315–346.

Sillitoe, R. H., and Bonham, H. F., Jr., 1990, Sediment-hosted gold deposits: Distal products of magmatic-hydrothermal systems: Geology, v. 18, p. 157–161.

Theodore, T.G., 2000, Geology of pluton–related gold mineralization at Battle Mountain, Nevada: Tucson, Arizona, University of Arizona and U.S. Geological Survey, Center for Mineral Resources, Monograph 2, 271 p.

Webster, J.G., and Mann, A.W., 1984, The influence of climate, geomorphology and primary geology on the supergene migration of gold and silver, *in* Davy, R., and Mazzucchelli, R.H., eds., Geochemical Exploration in Arid and Deeply Weathered Terrains, Exploration Geochemistry, Special Issue, v. 22, no. 1-3, p. 21–42.

Wang, Bing-heng, 1996, Geological characteristics of Huangshi Loashan-Mashan gold deposits, Tongling, Anhui Province, *in* Wang, Yongji, Qin, You-yu, and Chen, Peiliang, eds., Geology of iron, copper, gold, and silver mineral resources in the middle and lower reaches of the Yangtze River: Press House of Metallurgical industry, Beijing, p. p. 301–308.

Wang, Xichuan, ed., 1990, Geological Map of China, Explanatory Notes: Geological Publishing House, Beijing, 82 p.

Wang, Yuming, Jing, Chenggui, Wei, Zhenhuan and Yang, Qingde, 1996, The tectonics and its control on the gold-mineral deposits in the Tethyan domain of southwest China, *in* Liu, Yikang, Ma, Wennian, Wang, Yuming, Chen, Jing, Shen, Mingxing, and Miao, Laicheng, eds., Geology and Mineral Resources Proceedings of Ministry of Metallurgical Industry, p. 109–114.

Wang, Z., 1982, Complex model of copper metallogeny in middle-Middle-Lower Yangtze Valley and its significance for ore exploration: Scientia Sinica, ser. B, v. 25, p. 765–776.

Xu, Enshou, Jin Yuqui, Zhu Fengsan, Wang, Xiuzhang, and Yang Liansheng, 1992, Gold, Silver and Platinoid deposits of China, *in* Liu Nailong, ed., Mineral Deposits of China: Geological Publishing House, Beijing, v. 2, p. 294–349.

Yan Jiuping, 1996, The relationship between strata and metallizations in the lower- middle reaches of Yangtze River, *in* Wang, Yongji, Qin, You-yu, and Chen, Peiliang, eds., Geology of iron, copper, gold, and silver mineral resources in the middle and lower reaches of the Yangtze River: Press House of Metallurgical industry, Beijing, p. 1–18. (in Chinese).

Yan, Mei Zhong, and Hu, Kui, 1980, Geological characteristics of the Dexing porphyry copper deposits, Jiangxi, China: Mining Geology Special Issue, no. 8. p. 197–203.

Yin, A., and Nie, S., 1996, A Phanerozoic palinspastic reconstruction of China and its neighboring regions, *in* Yin, A., and Harrison, T.M., eds., The Tectonic Evolution of Asia: Cambridge University Press, Cambridge, p. 442–485.

Zhao, Y., 1991, Skarn deposits in the Circum Pacific belt: Mineral Deposits, v. 10, p. 41–51.

Zhao, Y., Lin, W., Bi, C., Li, D., and Jiang, C., 1990, Skarn deposits of China: Geological Publishing House, Beijing, 354 p.

Zhao, Yiming and Lin, Wenwei, 1993, Resource Geology, Special Issue, no. 15, p. 225–230.

Zheng, Z.M., Liou, J.G., and Coleman, R.G., 1984, An outline of plate tectonics of China: Geological Society of America Bulletin, v. 95, p. 295–312.

Table 5-1. $\delta^{34}S_{VCDT}$ for sulfide mineral separates, Middle-Lower Yangtze River area

Sample No	Mineral	$\delta^{34}S_{VCDT}$	Deposit
SP00001	sphalerite	+11.5	Xiaojiapu
SP00017	chalcopyrite	-1.6	Xinqiao
SP00018	chalcopyrite	+4.0	Xinqiao
SP00019	pyrite	+4.1	Xinqiao
SP00020	pyrite	+4.4	Xinqiao
SP00021	pyrrhotite	+6.7	Mashan
SP00022	pyrrhotite	+7.6	Mashan
SP00024	arsenopyrite	+7.7	Mashan
SP00025	pyrite	+3.8	Mashan
SP00026	arsenopyrite	+9.5	Mashan
SP00027	pyrrhotite	+4.1	Mashan
SP00028	pyrrhotite	-4.6	Huangshilaoshan
SP00029	pyrite	-9.3	Huangshilaoshan
SP00030	pyrrhotite	-7.6	Huangshilaoshan

Analysis from isotopic laboratory, Mackay School of Mines, University of Nevada, Reno
See Appendix IV for geochemical analysis and additional descriptions of samples. Analysis facilitated by Greg Arehardt and Simon Poulson.